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Entered at the Post Office at Lancaster, Pa., March 14, 1928, as second-class matter under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

Published by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

Prince and Lemon Streets, Lancaster, Penna., and
15 South Seventh Street, Philadelphia, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

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Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 212 SEPTEMBER, 1931 No. 3

COMING TO GRIPS WITH THE EARTHQUAKE PROBLEM.*

BY

N. H. HECK, Chief,

Division of Terrestrial Magnetism and Seismology,
U. S. Coast and Geodetic Survey.

On February 2 of this year we had another reminder that the problem of safeguarding cities against damage from severe earthquakes is as yet unsolved when the beautiful coast resort city of Napier, North Island, New Zealand, was nearly destroyed by a great earthquake. This earthquake also demonstrated that in designing structures to resist earthquakes the possible cumulative effects of a number of severe shocks must not be overlooked, since there were at least three aftershocks comparable with the main shock.

The earthquake is always of absorbing interest to the seismologist but we are rapidly approaching a condition in which the heretofore sporadic interest of the average citizen is being converted into continuous interest, in many parts of the earth, and accordingly the engineer and architect in the regions concerned are beginning to be quite as much interested as the seismologist.

The two fields of activity with regard to earthquakes—geophysics and engineering—while having different purposes, are not independent and results in either field may throw

* Presented at a meeting held Thursday April 2, 1931.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

light on the problems of the other. Prominent engineers have begun to criticize the seismologist for not giving them the information that they need, and the time now seems ripe for closer coördination of activity.

From the viewpoint of the geophysicist, earthquake investigation is for the purpose of learning all that there is to know about the nature of the earthquake itself as a physical phenomenon and the transmission of waves, and, incidentally, the nature of the transmitting medium, with consequent information about the interior of the earth which is obtainable in no other way. From the viewpoint of the engineer the important factors are the probable occurrence of a severe earthquake in a given locality, the effect of earthquakes on structures, and their design to resist, or reduce, destruction by earthquakes. There is particular interest in regard to the large structures which modern civilization makes necessary, such as office buildings, factories, bridges, high dams and other structures.

For a number of years engineers have been gathering information regarding earthquake effects on structures and to some extent are basing design of structures on the observed facts. They are also at Stanford University operating a large shaking table on which types of structure and models of buildings are tested under conditions simulating earthquakes. With all this, they feel the need of more exact knowledge in regard to motions of strong earthquakes, a demand which the seismologists have not yet met.

The reason for this is a practical one. Seismologists, like engineers, have to be practical. Severe earthquakes are of relatively infrequent occurrence at any given place, even where great damage has occurred in the past. Instruments suited to record strong motions will not record weak ones. Accordingly, in order that we may have material with which to work, the instruments must be able to record earthquake waves coming from a considerable distance, but instruments able to do this will not record strong motion. The valuable information which the seismologist has been able to obtain about the interior of the earth has been accompanied by the introduction of many perplexing problems. It is, therefore, not surprising that much energy has gone into perfecting

instruments and methods for recording distant earthquakes. In fact, the principal problems in this field are well on the way to solution, though we may continue to expect new instruments and methods from time to time.

The seismologist in developing these instruments has acquired much information which is useful for the design of the more rugged and relatively insensitive instruments which must be used to record strong motion. His knowledge of wave transmission will also be essential to the correlation of the information regarding strong motions when available. It is for the engineer to state exactly what information he needs and to make use of it after it has been obtained. The seismologist by his previous accomplishment has justified the confidence of the engineer in his ability to solve the problems.

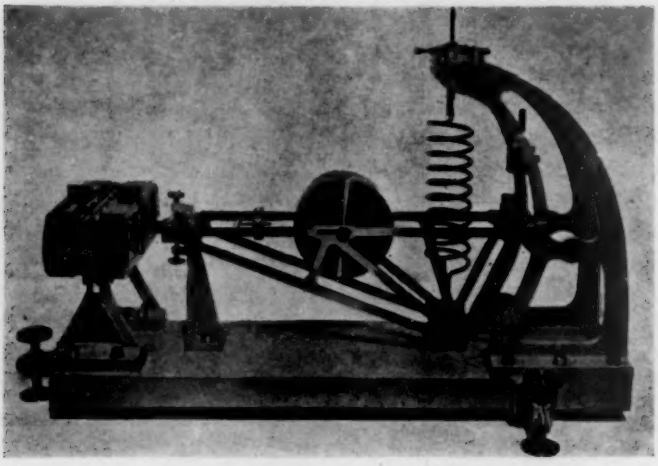
This accomplishment has included both instrumental development and the development of theories to explain the complexities of the records in terms of transmission through the earth and consequently reasonable deductions above the physical conditions of the otherwise unexplored medium through which the waves pass—the interior of the earth.

The working tool of the seismologist is the seismometer. The present efficient instruments are the result of attempts during the last fifty years, and especially during the last twenty-five years, to get truer records of the earth movements. Out of the many efforts to solve this problem a few features of design have survived and are embodied in existing instruments. This will be brought out in the description of the various features.

Since the earthquake wave occurs in a three dimensional medium, it is necessary to make observations along three axes at right angles to each other. There are usually two instruments for recording the horizontal component, identical but set at right angles to each other. There are difficulties in the design of a satisfactory vertical component instrument which add to the expense; and these are rarer, with many stations lacking entirely this important aid to earthquake investigation. Even with three components it is not easy to deduce the form of the waves. It has been found that when the direction from which the earthquake comes is nearly that of the axis of either component, the records are simplified.

Seismologists are, therefore, beginning to recommend that for any station the direction in which the greater number of

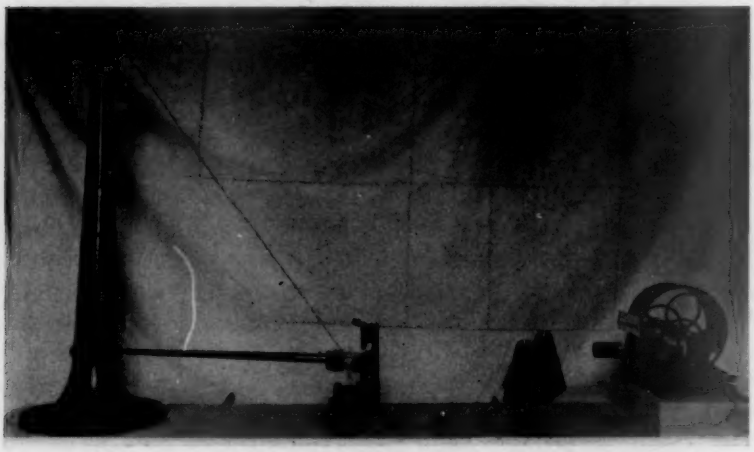
FIG. 1.



Galitzin vertical component seismometer.

earthquakes occur should be chosen as the direction of the axis of one component, the other, of course, being placed at right angles.

FIG. 2.



Tilt-compensation seismograph, McComb-Romberg type.

Horizontal Component Instruments.—In most cases the horizontal pendulum is used. See Fig. 2. The principle is somewhat that of a swinging gate or rather of a derrick with a horizontal boom. The boom carries a considerable mass, usually known as the steady mass, at or near its outer end, and this is supported in a number of instruments by a diagonal wire. The boom rests against a pivot so as to resist friction, and the wire is attached to the standard in such a way as to permit adjustment. The line joining the upper and lower points of support must be slightly out of the vertical in order to secure stability and high sensitivity. This arrangement makes damping easier than with a simple pendulum.

Damping.—This is necessary for the reason that if the earth wave period and that of the pendulum are nearly the same, resonance will be set up and there will soon be no definite relation between the ground movement and that recorded. Even if the period is somewhat different, an undamped pendulum soon ceases to give a correct representation of the ground movement. No matter what is done the reproduction of the ground movement will not be perfect, but the aim of the seismologist is to approximate it, and much can be gained by suitable damping arrangements. Damping may be air, oil, magnetic or electromagnetic. In most cases a vane suitably placed accomplishes the purpose. In the case of magnetic damping, a copper vane moves in a magnetic field.

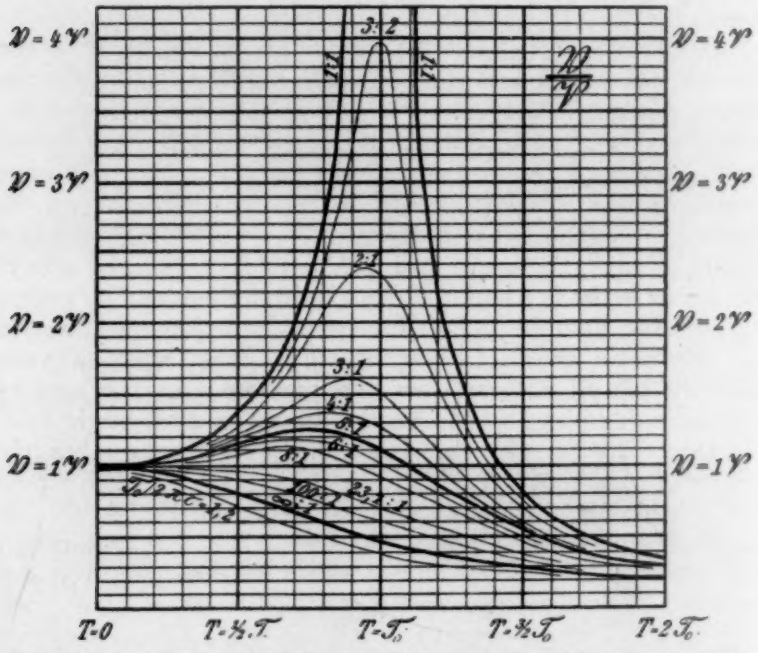
Magnification.—In the case of distant earthquakes the actual ground movement, if it were directly recorded, would be invisible for all but the very strongest earthquakes. For near earthquakes of considerable strength, the magnification must be small. There is in practice a wide range of requirements. Various instruments use magnifications of approximately 1200, 700, 150 and 5 or 2. For special purposes magnification of 1,000,000 has been used. By optical or mechanical means, the actual movement of the mass or, rather, of the supporting frame with respect to the mass, can be multiplied to a considerable degree and this is known as static magnification. For a record the magnification to be used differs from this and the so-called harmonic magnification varies with periods of earth wave and instrument and with the damping, and therefore for the same instrument magnification will vary with the earth period.

The formula for the so-called harmonic magnification is

$$W = \frac{V}{\sqrt{\left(\frac{P^2}{T^2} - 1\right)^2 + \frac{K^2 P^2}{K^2}}},$$

where W is harmonic magnification, P and T are respectively periods of earth wave and pendulum, V is static or instrumental magnification and K is the damping factor.

FIG. 3.



Relation between magnification of earth displacements, earth-wave period and pendulum period for different degrees of damping, according to Gutenberg.

Figure 3 gives a graphical representation of the harmonic magnification. The magnification curves for different degrees of damping are shown as functions of the ratio between earth wave periods and pendulum periods.

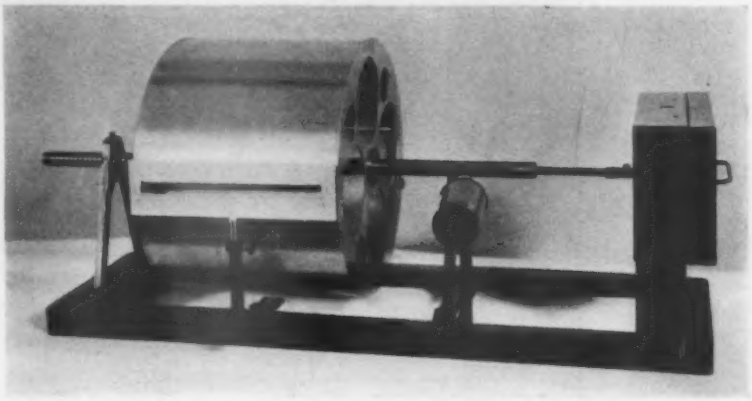
Period.—For recording nearby earthquakes, short period instruments are used both on account of the short periods to

be recorded and because of the necessary optical and mechanical requirements to obtain the desired magnification. In the case of distant earthquakes there is a wide range of periods and several might be chosen for the instrument. 12 to 15 seconds are in quite general use.

Vertical Component Instruments.—In these a mass is supported by a spring and the difficulty is to secure stability along with great sensitivity, large magnification, long period and freedom from changes due to temperature.

Time.—The accuracy of the time is of great importance. Uniform speed of rotation is one element and absolute time is another, and both must be satisfactory. Even with the best of apparatus, small departures from uniform rotation are likely and, therefore, it is desirable to have all components record on one drum or on several drums on the same shaft (Fig. 4). The same activity will not then be recorded at

FIG. 4.



Seismograph recorder, photographic.

different times because of variation in speed of several independent drums, and this is an advantage even if the absolute time is in error. Time marks from a good clock are placed on the record and time signals by radio are recorded directly on the seismograms, and if this can be done with sufficient frequency errors can be kept small (Fig. 5). Rev. James B. Macelwane, S.J., in a paper before the Section of Seismology,

International Geodetic and Geophysical Union, last summer stressed the importance of time and showed that there is grave danger of assumption at many seismological stations that the accuracy is greater than it actually is.

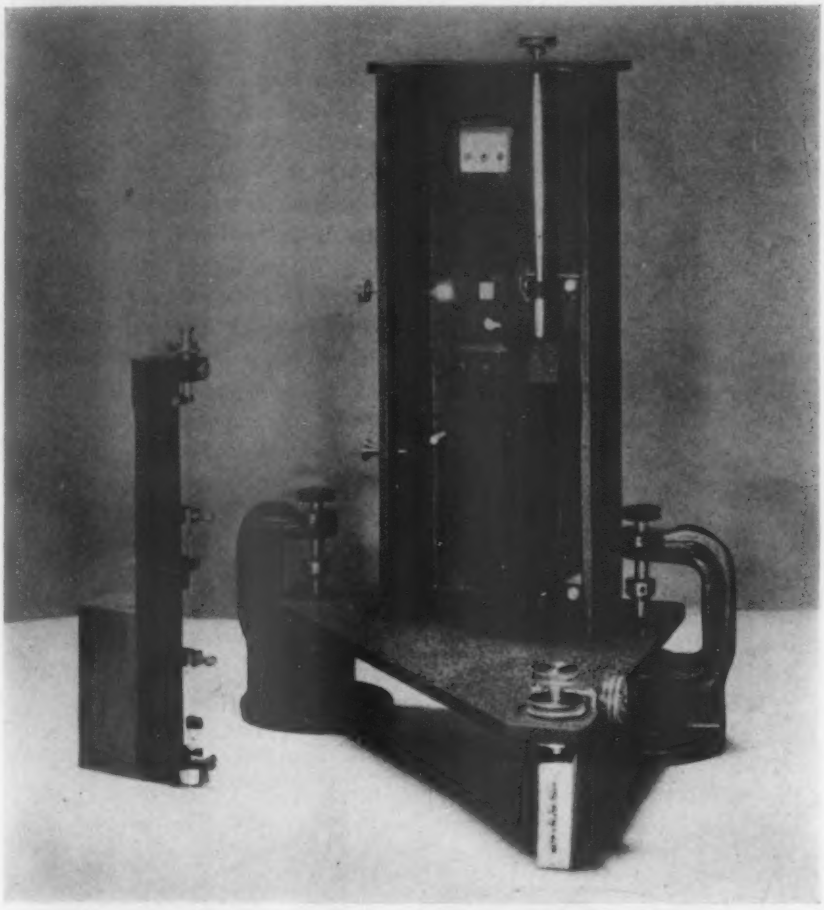
FIG. 5.

Pendulum clock for use in making time marks on seismograms.

Galvanometric Recording Systems.—In such systems the boom, in addition to carrying the mass, has a coil which moves in the field of a strong magnet. The currents set up are recorded through a galvanometer. This system has the advantages that high magnification can be readily obtained, damping is not difficult, and tilting of the pier is not recorded on the record. Also, it is at times a great advantage to have the seismometer at a place specially suited to this purpose and

the recorder at another place at some distance away, where conditions are better suited for recording. The distance may be considerable if conditions demand this.

FIG. 6.



Wood-Anderson torsion seismometer with suspension removed.

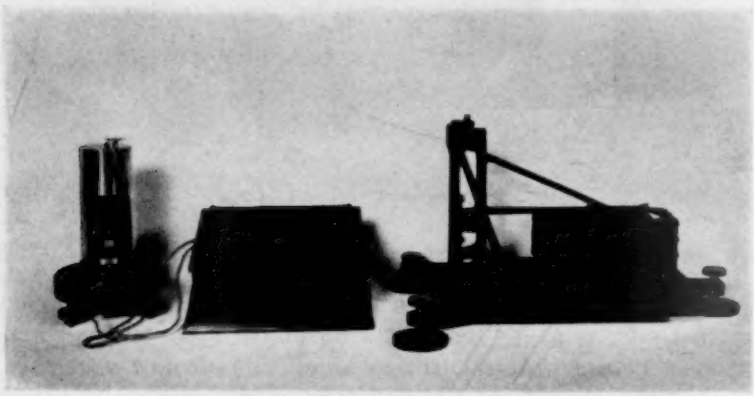
In the case of most horizontal component instruments with long periods, as 12–15 seconds or more, tilting of the pier may seriously confuse the record. The effect is to put successive lines on the record too far apart or, more serious, to crowd

them so close that an earthquake record cannot be interpreted. This tilt is usually due to local temperature effects on the building or on the pier itself. The effect of tilting is eliminated in the galvanometric recording system and in the case of short period instruments, and it is very desirable to eliminate it on other types. This has been accomplished successfully in an instrument which will be described later.

Examples of instruments which embody these principles.

Wood-Anderson Torsion Seismometer.—Fig. 6. This instrument through use of a very small cylindrical mass or a vane attached to a vertical fiber under tension, is able to get a short period with high magnification and so is able to respond to, and to magnify, ground movements of very short period. It is probably the best instrument in existence for the study of nearby earthquakes. It was developed at Pasadena, California, for the special studies that are being made there. While ordinarily operated at a period of less than one second, it has been operated at 6 seconds, and the Coast and Geodetic Survey is operating such an instrument at Tucson, Arizona. It not only gives good records of distant earthquakes but gives useful records of earthquakes at moderate distances, as in the Imperial Valley and elsewhere in Southern California and adjacent Mexico, so that the records are useful in connection with the special investigations being made in Southern California.

FIG. 7.



Wenner horizontal component seismometer and equipment.

Galvanometric recording is used in the Wenner seismometer, developed by Dr. Frank Wenner of the Bureau of Standards (Fig. 7). This instrument has been fully described in publications of the Bureau of Standards [1] available to anyone interested. It is operated at high magnification and gives exceptionally good records except when microseisms interfere with interpretation of the records. These instruments are installed at San Juan, Porto Rico, at the observatory of the Coast and Geodetic Survey, at the Cathedral of Learning at Pittsburgh, Pennsylvania, and will soon be installed at the station of the Massachusetts Institute of Technology near Machias, Maine, and at the observatory of the Coast and Geodetic Survey at Sitka, Alaska, and also in the new Franklin Institute Museum in Philadelphia.

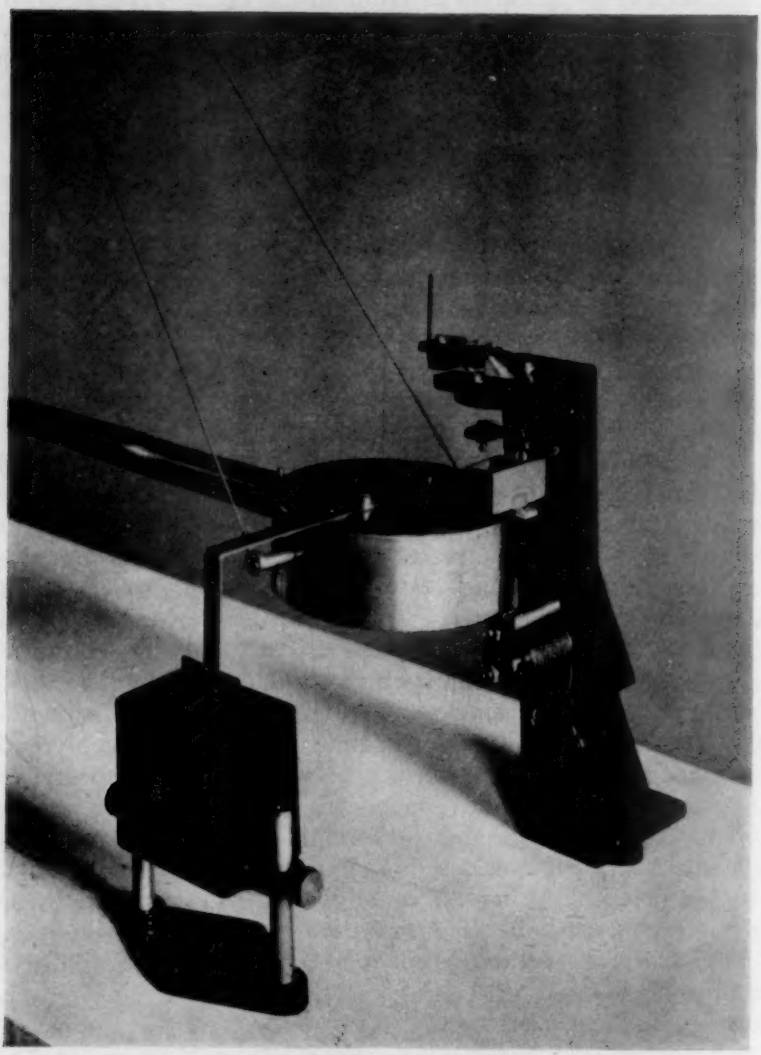
The McComb-Romberg tilt compensation seismometer has tilt compensation in effective form. See Fig. 2. The instrument has been developed by H. E. McComb of the Coast and Geodetic Survey, using a principle developed by Arnold Romberg, now of the University of Texas, but at the University of Hawaii when he did the work (Fig. 8). The instrument has photographic recording with relatively simple and compact optical system, oil damping, and magnification of about 150. Its distinctive feature is oil coupling between boom and recording mirror. The mirror which is horizontal has a vertical stem or shaft which carries a vane. The vane is free to move in a long rectangular container of castor oil, which is attached to the steady mass. The mirror is pivoted on a horizontal axis so that it tilts with every movement of the vane. All rapid movements are transmitted from liquid to vane as if the connection were rigid. If, however, owing to tilt, the boom takes a new position, the vane drifts through the liquid with the mirror remaining horizontal. Since the tilt and drift are both very slow the record is not affected.

With the instruments that have been described or others with similar characteristics, it is possible to have seismograms to meet the needs of particular investigations.

When we realize the immense complexity of the earthquake waves and the possible reflections and refractions, it

[1] A New Seismometer, etc., Research Paper No. 66, Frank Wenner, reprint from *Bureau of Standards Journal of Research*, Vol. 2, May, 1929.

FIG. 8.



Multiplying lever, bracket and damping vane of McComb-Romberg system.

would seem reasonable that we could distinguish only the arrival of each type of waves and that the rest would be hopeless confusion. This is not the case not only because waves resulting from reflection and refraction have enough energy to stand out above the rest but because there is a sorting process due to distribution of the original energy which makes certain activity to stand out, and others to disappear. It is this that not only makes it possible to interpret the record but to learn something about the interior of the earth in which the sorting process occurs.

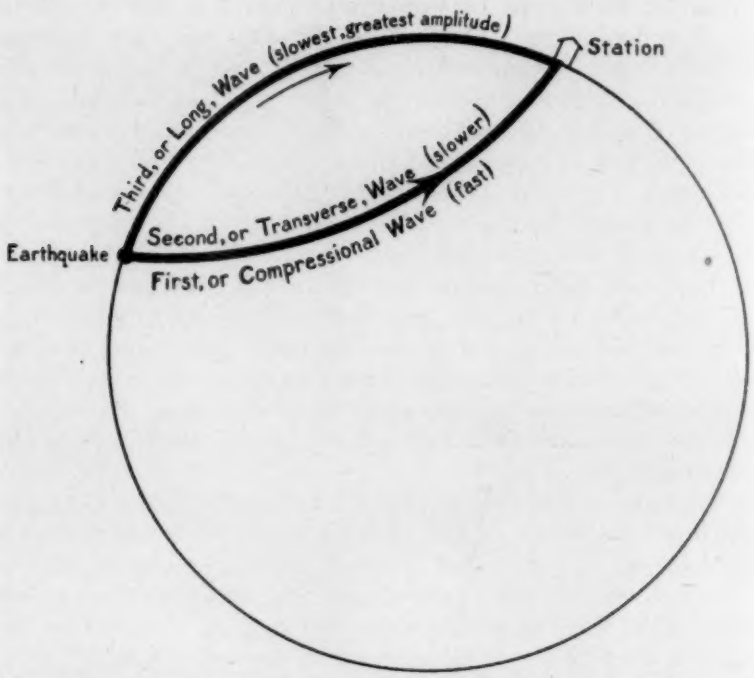
There are then definite arrivals of so-called phases which are indicated by sudden or gradual increases of amplitude or by sudden change of period, or both, and these form an orderly succession, some of which can be distinguished in all intelligible records. Since many of those present have probably not gone far into the subject, I will recapitulate the principal facts.

We have the preliminary tremors, designated *P* for primus, which are longitudinal, that is, with vibration in the direction of progress. These follow a direct path from earthquake to recording station but a curved one, dipping somewhat below the straight line connecting these two points. Their velocity near the surface is 7–8 kilometers per second and their ordinary period 5 to 7 seconds. The second preliminary, designated S for secundus, is a transverse wave with vibrations at right angles to direction of progress. The velocity near the surface is about 4.5 kilometers per second and the period is 11–13 seconds. The path is approximately that of the *P* wave.

Reflections of these waves may occur at the earth's surface at the halfway point or even at two points respectively one-third and two-thirds of the way with sufficient energy to be recorded. The first case is designated as PR_1, SR_1 and the latter PR_2 and SR_2.

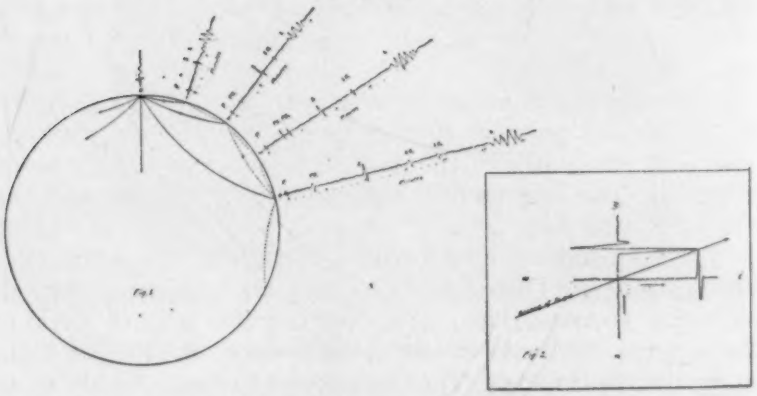
The longitudinal waves which pass along the surface are more complex. Their speed is 3 to 4 kilometers per second, according to conditions. The velocity for a path entirely beneath the Pacific Ocean is about 20 per cent greater than under the continents. The directions of vibrations are more varied than for the preliminary waves. The periods vary

FIG. 9.



Difference in times of arrival of first and second waves gives distance from earthquake to station.

FIG. 10.



Paths of earthquake waves and types of seismogram at different distances from the epicenter. Insert, method of estimating azimuth of disturbance.

greatly and may be very large, as 40 seconds or even a minute.

While much more might be said, these statements give the essential facts. It is not, however, the whole story. When the distance exceeds 10,000 kilometers, the waves pass through the central metallic core of the earth and this modifies the paths so that the system of phases that has been described is replaced by another. However since my purpose is to discuss the central and surrounding region of an earthquake, I will not go into this.

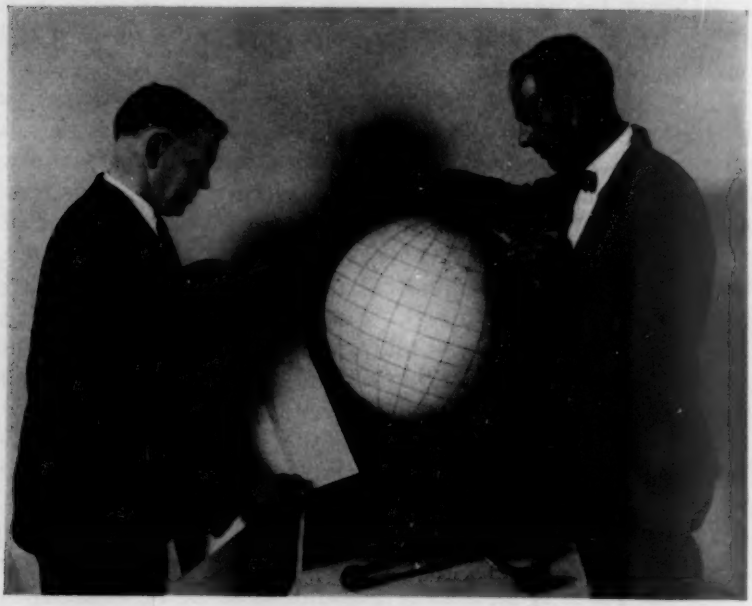
The actual use of the complex phases is made possible through diagrams with distances plotted as ordinates and interval in seconds from time of origin of the earthquake as abscissas. Tables are also used in which time intervals from time of the earthquake to arrival of the given phase, or intervals between successive phases, are given for each distance. Perhaps the most convenient tables that have been developed are those of Rev. James B. Macelwane, S.J., of St. Louis University. However, not all tables are in full agreement and seismologists are still working on the best values to adopt in some cases.

An important use of these diagrams and tables is to obtain distance of station from earthquake in order that the earthquake epicenter may be known. The epicenter is the point on the surface directly beneath which the earthquake occurred. This can be located in several ways but the graphical method of plotting on a large globe need alone be mentioned. Some years ago little use was made except of records giving clear *P* and *S* phases. Now earthquakes can be located when these phases are lacking on all available records. Such a location was made of an earthquake in China which later was found to agree with the determination made from all available data, including those of near stations. An adopted epicenter must meet the requirement of reasonably good intersection of the arcs, and the times of origin of the earthquake as computed from the several records must be in good agreement.

The tables and curves have been derived from study of records and from theory. Certain assumptions are made and if these agree with a large mass of observational results they are held to be valid.

In this way a solution can be found for the distribution of density within the earth. Knowing the surface density and the mean density as given by astronomy, a distribution can be worked out which fits the velocity of seismic waves at all distances.

FIG. 11.



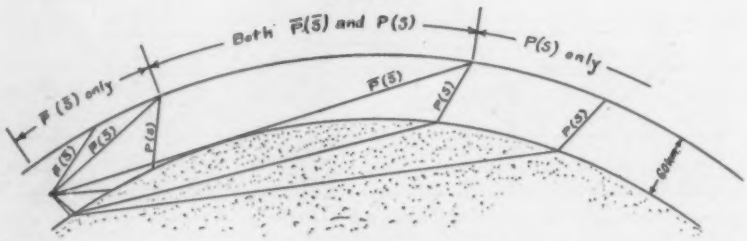
Location of an epicenter on a 30 inch globe at the U. S. Coast and Geodetic Survey, Washington, D. C.

If the observations fit adopted curves through a wide range and then the agreement suddenly disappears, an explanation must be found; in this way the existence of certain layers of discontinuity has been postulated. The best known and most definite of these is that at 2900 kilometers which bounds the central core of the earth which geologists believe to be of iron and nickel. The ability of this core to change path and energy of the earthquake waves is beyond argument. It has also been held that the condition of the interior, though of very high pressure and temperature, behaves like a liquid in its inability to transmit any but longitudinal waves. Transverse waves are practically lacking, though Dr.

Macelwane [2] has recently found evidence that they may exist, though feeble.

Of more importance to our discussion are layers near the surface. These are not so definite and there is more difference of opinion. In records of nearby earthquakes there are often two *P* phases and sometimes three, and the same may be true of *S*. An explanation is called for. The first was that of Mohorovicic who postulated a layer of discontinuity sixty kilometers beneath the continents, and this seemed to give fairly good agreement with observations (Fig. 12). Changes

FIG. 12.



Showing effect of supposed 60-kilometer layer upon longitudinal and transverse waves. Reflections not shown.

in velocity throughout the layer in a similar manner for that worked out for the deep interior of the earth were necessary. Observations of submarine earthquakes gave evidence of a much thinner layer beneath the oceans and this in turn corresponds to the faster surface waves beneath the oceans which have been mentioned.

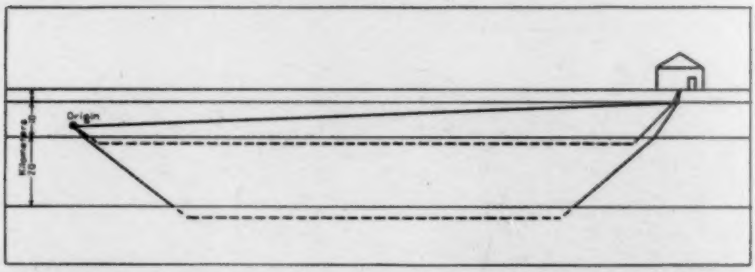
Seismologists in general had accepted this conclusion almost universally when Jeffreys suggested a different explanation. As shown in Fig. 13, his theory calls for two layers of discontinuity about ten and thirty kilometers, respectively below the surface. Most of the energy passes along these surfaces and the velocity of the waves remain nearly constant throughout their paths. Seismic prospectors use a somewhat similar theory for layers very near the surface. Investigations in California fit Jeffreys' theory very well.

The consideration of these layers brings us to a very

[2] South Pacific Earthquake of June 26, 1924, J. B. Macelwane, S. J., *Gerland's Beiträge zur Geophysik*, Vol. 28 (1930).

important question—the depth of focus or depth beneath the surface at which the earthquake occurs. This is of importance in the case of distant earthquakes but it is far more important for those occurring nearby. Theoretically there should be important differences in the records of two earthquakes at the epicentral distances of, for example, 200 kilometers, but with one having a depth of twenty kilometers and the other forty.

FIG. 13.



Paths of preliminary earthquake waves through upper layers of earth's crust according to Jeffreys.

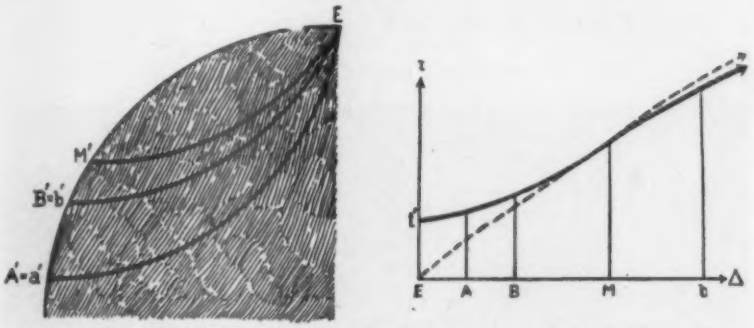
Methods for determining depth of focus are not yet satisfactory and in order that such determinations may be undertaken, there must be a large number of precise records from nearby stations, and time must be accurately measured to the nearest tenth second. The latter requirement is met at very few stations, and the former only in parts of Europe and in Japan, though before long the eastern and extreme western portions of the United States should meet this requirement. Sieberg[3] gives for a European earthquake depths ranging from 133 to 40 kilometers according to the method adopted, with 45 to 60 as the most probable. Gutenberg arrives at 50 kilometers as about the average depth for moderately severe earthquakes.

A typical method will be described briefly. It is obvious that near the epicenter, the time from focus to station will be greater than if the earthquake is at the surface. At some distance the reverse will be true. The distance from the epicenter to the point at which the times are equal is directly related to the depth of focus. It is obvious that it is not easy

[3] Sieberg's *Erdbebenkunde.*

to adjust the data to secure the most probable value of all the elements but it can be done. However the method is weak since very small errors in time introduce errors in depth of focus. Other methods depend on reflection from layers of discontinuity, though a difficulty here is that a definite theory as to these layers must be adopted.

FIG. 14.



Graphical method of determination of depth of focus. (From Gutenberg's Grundlagen der Erdbebenkunde.)

In the case of the Japanese earthquake of Sept. 1, 1923 there were enough records made by strong motion instruments with three components nearby so that a simpler method, and one independent of time, could be adopted. The observations [4] were so near the epicenter that it could be assumed that the angle of emergence of the waves gave directly the direction of the focus on the assumption of straight line transmission. The distance of observation points from epicenter ranged from 70 to 132 kilometers. The depths ranged from 35 to 55 kilometers with 48 as the average. This is interesting in view of Gutenberg's adopted 50 kilometers. This method becomes uncertain at distances greater than 200 kilometers both because the ratio of depth to distance is becoming small and because straight line transmission can no longer be assumed. There is still much work to be done on this problem.

The matter of transmission and dispersion of energy is of fundamental importance. There has been much mathe-

[4] Memoirs of Imperial Marine Observatory, Kobe, Japan, Vol. 1, No. 4, 1924.

matical discussion. Knott follows the so-called classical theory of reflection and refraction of waves at surfaces of discontinuity with brachisotochronic paths based on the principle of least work. Jeffreys' theory requires a large part of the energy to take a path along the surface of discontinuity.

When we come to the central region of strong earthquakes, we find conditions of great complexity. Observations by adequate instruments are so few that we are driven to study earthquake effects as the best guide to what has occurred, a

FIG. 15.

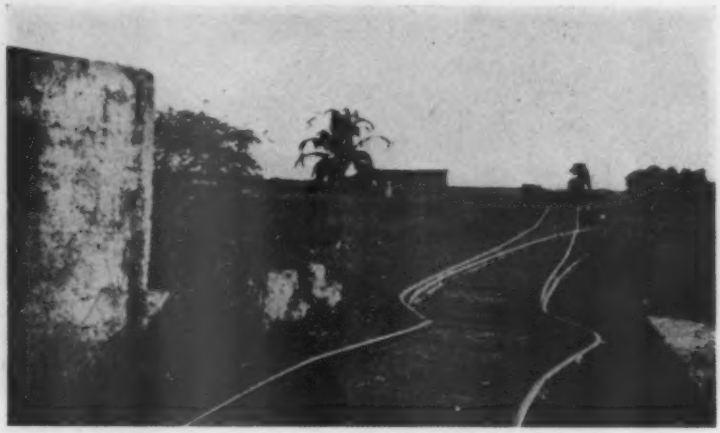
Destructive effects of Japanese earthquake of 1923, Yokohama.

method obviously defective. Men under mental stress are not capable of making observations with the impartial attitude of a machine. However, invaluable information is obtained from such reports and when a phenomenon is reported by many witnesses which seems to conflict with the known principles of earthquake wave behavior, a careful investigation should be made. As an illustration, in regions of deep alluvium or of a moderately thick layer of soft material, earthquake waves have been seen to pass over the ground in a manner similar to the ground swell of the ocean.

In the case of the California earthquake of 1906, sixteen persons in as many different localities reported seeing such waves. Similar reports were made in the case of the Porto Rican earthquake of 1918 and there have been many other examples.

At first thought this might seem not unreasonable, but it must be remembered that while earthquake waves travel at least two miles per second, the ocean swell rarely exceeds 65 feet per second. It is therefore difficult to comprehend how we can see the waves pass along. Crests of such waves have been reported as two feet above the troughs, but, even if the phenomenon is genuine, the probability is that the

FIG. 16.



Subsidence of the ground with consequent tilting of buildings in the Victoria Battery, Port Royal. The kink in the railway track is over a fault.

height does not exceed six inches. It will be interesting to learn the facts by instrumental observation. In some cases a series of parallel cracks in the earth have been found parallel to the crest of the reported waves. Even then the waves may be an illusion due to the effect of the earthquake itself on the observer.

Railroad tracks sometimes afford evidence that strong forces have been at work. In some cases the distortion appears to have been due to shortening but it is not clear how

this shortening has been brought about. No effort has been made to analyze the forces. The directions taken by falling monuments in cemeteries bear witness to the variations in the forces at work. Often the majority will fall in the same directions, but the remainder will fall at an angle with, or even at right angles to, the prevailing direction. There are many striking examples of turning of a monument on its base, or even of different parts of a monument by different amounts, but without fall.

FIG. 17,

Derailment of train of cars due to California earthquake of 1906. Photograph by U. S. Geological Survey.

The effects on buildings are of interest. In many cases the destruction is so great, or the failure so varied, that they are not instructive. Much can be learned, however, from study of selected details. It is, however, very difficult to deduce the actual earth movements in this way on account of the complexity and variation in the stress applied and our lack of knowledge as to just what part of the activity produced given results. But even then much can be learned, and a large part of existing effort to prevent damage from earthquakes has been obtained from the study of damaged build-

ings. Much work has been done in Japan by the Earthquake Research Institute and other organizations, and buildings are being erected which are expected to resist destruction, or even serious damage. The report of the great earthquake of

FIG. 18.

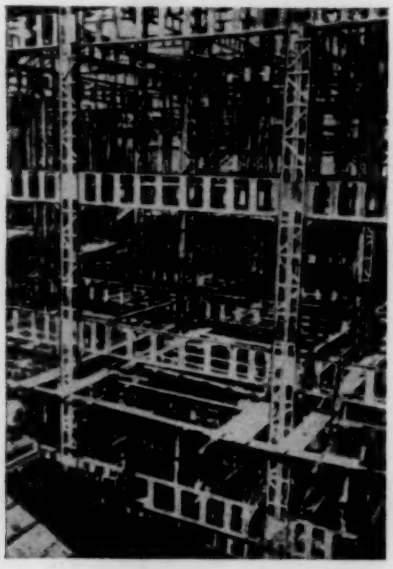
Displacement of cemetery monument due to earthquake.

September 1, 1923 contains much valuable information but is not yet available in English.

Similar studies have been made in Italy and the United States, though in this country the work is just beginning to be organized on a proper scale. There is great lack of infor-

mation and one of the important needs is for instrumental records in the vicinity of buildings that are damaged in an earthquake. Design involves the use of formulas and it is the so-called constants in the formulas which are not satisfactorily known. One of the most important of these is the maximum acceleration; without certain knowledge of this the engineer is not sure of his factor of safety.

FIG. 19.



Earthquake resisting construction, Tokyo, 1929. Photograph by R. R. Martel, Courtesy of John R. Freeman.

We have all sorts of statements as to the relation between acceleration and damage, and the so-called Mercalli-Cancani scale of earthquake intensity is a double scale of equivalents. Engineers are beginning to adopt 0.1 acceleration of gravity for maximum horizontal and 1/20 g. for vertical acceleration. In Italy higher values have been adopted up to 1/6 g. This must be considered in the light of the fact that we have few instrumental determinations of accuracy.

There has been no lack of effort to make such determinations. A favorite device consists of a series of small columns

side by side so arranged that each will fall when a given acceleration has been reached. The results leave much to be desired both because there is but a single observation and the time is not known, and it is never certain that the column which has fallen may not be too high in the scale on account of resonance effect, or rather the addition of successive impulses.

Other attempts have been made to deduce the maximum acceleration from the fall of objects. Here again we do not know whether there has been a single impulse, or the accumulated effect of several. A typical example of the straits to which seismologists and engineers have been driven is the attempt of Bailey Willis to deduce this information in the case of the Chile earthquake of 1922 from the fall of boundary walls of adobe. Unfortunately the bottoms of the walls were weathered and somewhat rounded and this vitiated the conclusions. It is obvious that instrumental observations alone will give the true values of the acceleration. Acceleration, however, cannot stand alone as the sole cause of destruction. It is the combination of acceleration, period, duration of the shock and perhaps the number of periods of strong shock which cause the destruction. Imamura [5] gives an example of an earthquake occurring in March, 1930, in Japan where the recorded acceleration was 0.8 g. but the period and duration were both very short and no serious damage was done. It is obvious that records to be useful must give all these factors accurately.

These observations, when made, should be competent to decide the question of the existence of surface waves of considerable amplitude and of low velocity which have been mentioned. It is also important to learn more about the differences in the effects of earthquakes which rupture the surface and those which are of great intensity but too deep to cause such rupture. Of particular interest are the vibrations set up by visible slipping along a fault plane. We know from isoseismal lines (lines of equal earthquake intensity) that there are differences between the volcanic earthquake, or other earthquake originating at a point or in a very small

[5] On the Recent Ito Earthquake, A. Imamura and others, *Proceedings Imperial Academy*, Vol. IX, No. 5, May, 1930.

area, with nearly circular isoseismal lines and with energy going out in every direction equally, and the earthquake originating along an extended fault line with elongated isoseismals.

Observations of a few strong earthquakes in their central regions will not solve all these and other problems. The possible number of combinations are very great. However, with an effective program the accumulation of information will be steady.

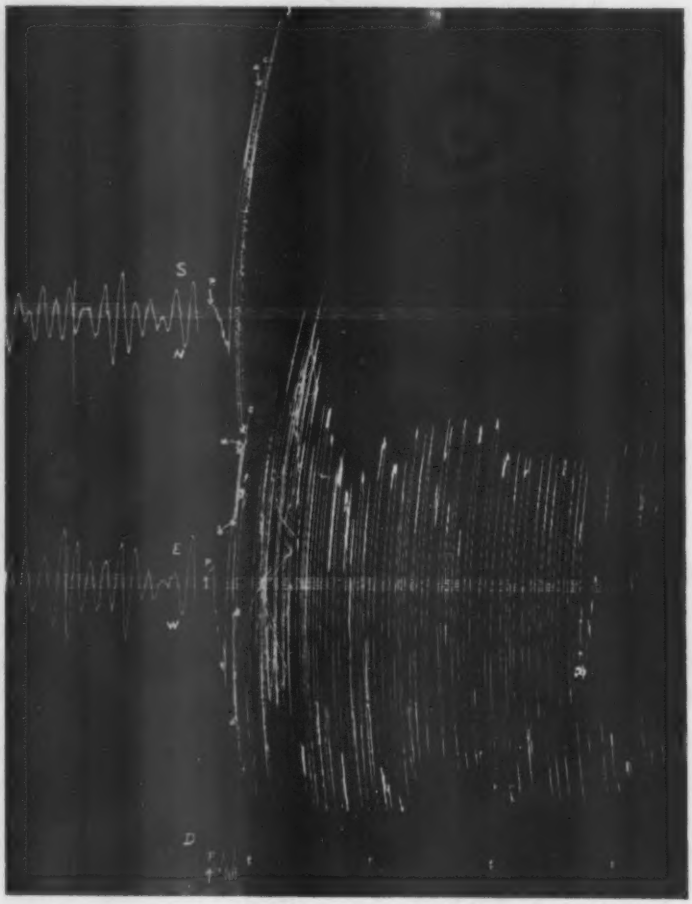
The recent New Zealand earthquake (February 2, 1931) has shown, as have many others, that certain types of earthquake damage are inevitable. Types of construction matter little if the building is directly over a fault line with horizontal or vertical slipping or in the path of a great landslide. If a great tidal wave occurs buildings in its path will be swept away. However. for most earthquakes the number of buildings exposed to these special hazards is not a large proportion, and the most common needs are ability to resist strong shocks, and fire prevention. In both these fields there are important possibilities. Earthquakes are no more numerous or more severe than in the past but the earth is so much more intensively occupied that the risk of important damage is greater than ever before and is constantly increasing.

The problem then is prevention of disaster due to moderately severe earthquakes and reduction of damage due to great ones. Engineers are beginning to agree that major structures should be designed with regard to earthquake stress if the history of the region indicates that they are likely to be subjected to such stress. They are recognizing the lack of information and are demanding that more accurate information be obtained.

In view of these statements, it is of particular interest that Congress in making provision for the work of the next fiscal year, has provided for the start of this work: it should be in effective operation by the end of 1931. I am about to proceed to the Pacific Coast to consult with various organizations and develop an adequate plan. In starting the work in that region, it does not mean that this is the only region where strong earthquakes occur. In fact, the most severe earth-

quakes in this country during the past five years have been in the East, but it is a region where earthquakes of severity have occurred in a number of localities and therefore with

FIG. 20.



Seismogram made at Tokyo of great earthquake of September 1, 1923. Magnification ⅓. Photograph by Bureau of Social Affairs, Japan.

suitable distribution of instruments earlier results may be anticipated there than elsewhere. Furthermore, the demand for this work comes from that part of the country where a

sentiment of wise preparedness for possible emergency is being developed.

The purpose is to install instruments capable of recording accurately strong earthquake motions in places where history indicates that there is probability of earthquake activity of some intensity. It is regrettable that such instruments were not installed in New Zealand last February when invaluable information could have been obtained. However, instruments of a satisfactory character were not in existence, nor are they today, except for several types that have been developed in Japan which are adapted to frequent, strong activity (Fig. 20). In this country the Bureau of Standards, the Coast and Geodetic Survey, the Massachussetts Institute of Technology and the Earthquake Research Laboratory at Pasadena are all at work on the development of such instruments, and it is expected that satisfactory instruments, even if not of the ultimate type, will be available before the end of the present year.

It would be premature to describe instruments which, though in process of development have not yet been tested, but a few fundamental principles may be mentioned.

It is not necessary to have elaborate piers separated from the floor of the building as for teleseismic instruments, but these strong motion instruments may be placed directly on a basement floor or preferably on a block of concrete resting on the floor. The principle by which early recorders were set in motion by the earthquake, long since abandoned because the important earlier and weaker phases were lost, is being revived in different form. With a continuously turning drum and with photographic recording started by the earthquake the objections are met with resultant great economy of operation.

If we know the acceleration, amplitude and period, other desired information can be deduced. The proposed instruments will be capable of recording accelerations up to at least 1/5 g. and simple devices will also be available which will record accelerations up to the value of g, though with no such complete record as for the instruments just mentioned. The instruments themselves will have to be safeguarded to resist destruction from earthquake.

Earthquakes are in many cases related to movements of

the earth's crust which may occur at the time of a severe earthquake or during the interval between great earthquakes. The only satisfactory way to determine such movements is by precise triangulation and leveling repeated at suitable intervals. Much work of this sort has been done in Japan, especially leveling, with significant results. In this country triangulation was executed in California after the earthquake of 1906 which determined the local movements. During the last few years, as the result of a special appropriation by Congress, triangulation has been executed in California with connection to undisturbed regions to the east and the plan includes repetition of the observations from time to time. A similar situation exists in regard to precise levels, though more of this work remains to be done. It has been pointed out by geologists that though practically all of the movement in the 1868 and 1906 California earthquakes was horizontal, geological studies indicate prevailing vertical movements in the past.

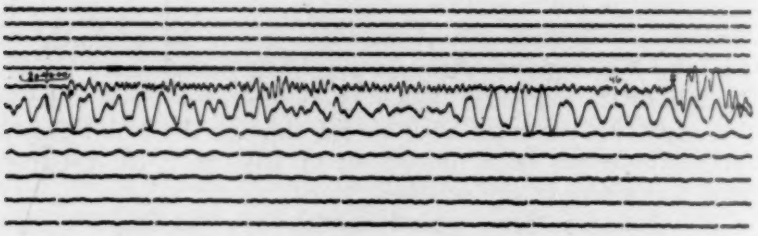
This work has required high accuracy and it has been strengthened both by complete adjustment of all the triangulation of the western half of the United States and also by the establishment of Laplace stations in the region of the special triangulation. At these stations complete astronomical observations are made and these are combined with the geodetic observations in such a way as to improve the azimuths of lines and consequently the geographical positions of points throughout the scheme. While there are a few cases of large movement, there seems little doubt that at the Point Reyes station there has been movement of $10\frac{1}{2}$ feet, the greatest found anywhere in the scheme.

The Japanese have added another type of investigation that they have found very useful. Even before the days of instrumental observation, as far back as 1793,[6] the inhabitants of a coastal village noticed a sudden change in the sea bottom and assuming that it meant the arrival of a tidal wave they rushed to the hills. Nothing occurred for four hours. Then came a great earthquake and tidal wave. This phenomenon

[6] Publications of the Earthquake Investigation Committee in Foreign Languages, No. 25, Topographical Changes accompanying Earthquakes or Volcanic Eruptions, Tokyo, 1930.

has been observed to a lesser degree in other earthquakes and the natural assumption is that the surface of the earth tilts just before the earthquake. In four earthquakes the intervals have varied from a half to four and one-half hours. Recently instrumental observations have been made of the tilt of the ground which confirms the earlier observations and indicates that in Japan at least the tilting of the ground is significant. This does not refer to local tilts due to temperature which the tilt compensation seismometer eliminates but it is a long period tilting of the ground in regions subject to severe earthquakes with rapid tilting just before the earthquake. If it can be definitely established that this is common to all earthquakes in Japan, even when the amount is less than can be readily perceived, it may be possible to give an advance notice of a few hours which might be invaluable. The Japanese have developed a tiltmeter, and another instrument for this purpose has been designed at the U. S. Bureau of Standards but has not yet been constructed. It is important to learn whether this phenomenon is peculiar to Japan or any other region where there is block faulting on a large scale, or whether the same thing will be observed in this country.

FIG. 21.

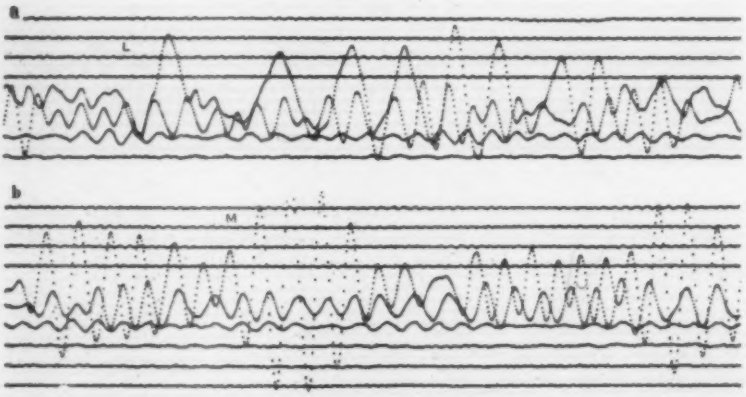


Record made by Wood-Anderson seismometer at Tucson magnetic observatory, Tucson, Arizona on November 18, 1929. Grand Banks earthquake. E-W component.

My purpose has been to show that a program of earthquake investigation is being developed which when added to the already well organized plan will fill important gaps in present knowledge. Stress has been laid on fundamental principles, instruments and methods and this serves to emphasize that we are still in a stage when these are the all important things. We are beginning to utilize the records to find out facts about

the earth but there is great room for expansion in this field. There are two great fields of investigation—that treating the earth as a whole or dealing with a substantial portion of its crust such as the area of the United States; and the local investigation as exemplified by the investigations in California under the auspices of the Carnegie Institution of Washington, the California universities and other organizations, by the investigations in the Mississippi Valley under the auspices of St. Louis University and the National Research Council and the plan of the Coast and Geodetic Survey for coöperative observations chiefly for the benefit of the engineer.

FIG. 22.



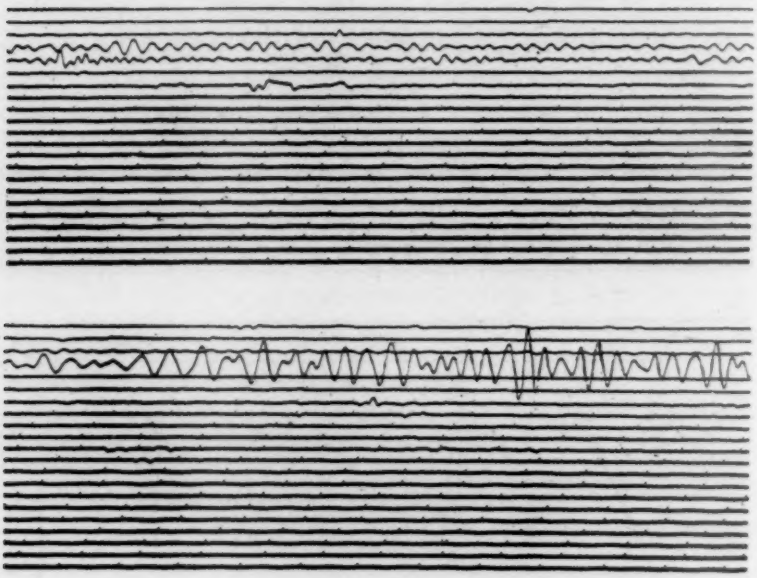
Seismogram recorded by Wenner horizontal component seismograph at U. S. Bureau of Standards, Washington, D. C.

The studies with regard to the United States as a whole are carried on by the national government through the Coast and Geodetic Survey with the coöperation of the Weather Bureau, the Geological Survey, Bureau of Standards and the National Research Council; the members of the Jesuit Seismological Association; the universities and colleges in different parts of of the country. The eventual aim is to keep informed in regard to the elastic condition of the earth's crust.

It is in this field that the Franklin Institute can take an important place. The map of earthquake activity shows that the vicinity of Philadelphia, though not entirely immune from earthquake activity has never had anything but rela-

tively feeble shocks. This is, however, an ideal condition for a seismological station which deals with other than local shocks. There is one feature of special interest and that is that seismologists find a series of stations in a straight line specially useful in dealing with wave transmission and Philadelphia lies in the line of existing stations and of earthquake areas in central and western South America. The

FIG. 23.



Seismogram made by McComb-Romberg seismometer, recorded at Washington, D. C., on January 27, 1931. Epicenter not definitely located but probably in southeastern China.

proposed station would also be an important addition to the world chain of seismological stations and would give your institution a share in the fascinating work of treating the earth as a laboratory. Recently Dr. Merriam, president of the Carnegie Institution of Washington, in a lecture which I attended, showed that the Grand Canyon exhibits to the eye practically the whole range of geological history. The seismologist, even though he cannot see beneath this depth of one mile is able alone to penetrate to the center of the earth.

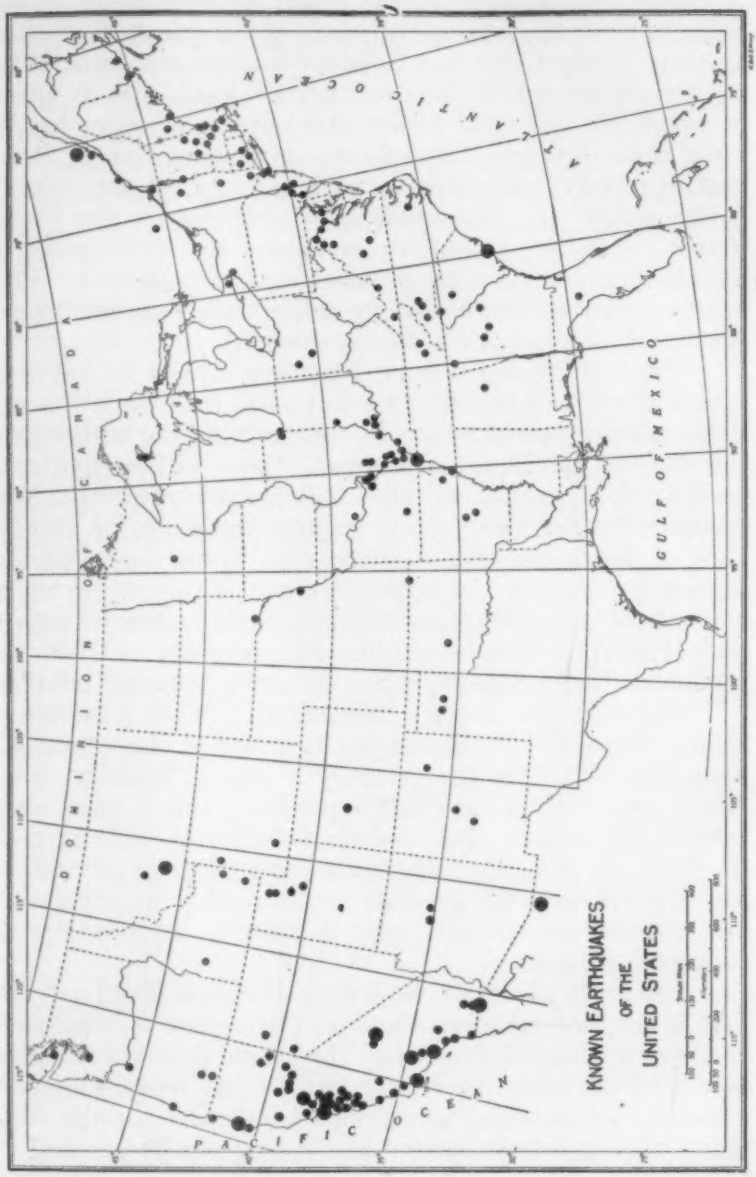

KNOWN EARTHQUAKES
OF THE
UNITED STATES
DOMINION OF CANADA
GULF OF MEXICO
PACIFIC OCEAN

FIG. 24.

Many are thinking of the future of seismology. I am going to close by quoting the views of Captain R. S. Patton, Director of the Coast and Geodetic Survey, who in addition to his administrative relation to the work, has a strong personal interest in the future development of seismology so as to meet all needs. In a recent statement he said: "I feel that in recent years we have made most gratifying progress in our attack upon the problems of seismology in the United States. I cannot too highly commend the little groups of men by whom that progress has been accomplished. They have not only worked untiringly individually but their coöperation with one another has been splendid.

"But I also believe: first, that there is need for increased future effort, and second, that any such increase will necessitate a more formal means of coördinating the activities of the various participating groups. There will be particular need to clarify, and to dovetail together, the respective fields occupied by the two general groups consisting, on the one hand of the geophysicists, concerned with the pure science of seismology, and on the other hand the engineers, architects and others who are concerned with earthquakes because of their potential menace to life and property. These two groups are still groping toward the proper mutual relations.

"Coördination implies leadership. The coördinating agency certainly should not try to preempt the whole seismological field. On the contrary it may contribute only a minor part of the total effort expended. But it must maintain at all times a clear vision of the entire field in order promptly to detect any failure of uniform progress throughout, and it must have the prestige to insure that its conclusions are respectively received and, if possible, adopted by the coöperating agencies.

"I see only two possible sources of such leadership. The first is the Federal government. The second is a privately endowed institution directed by the master minds of the whole field. Of the two, I prefer the latter. My reasons are complicated, but perhaps I can summarize them in a single statement, that a federal agency would scarcely be granted the freedom of initiative which it needs in order to function effectively in such a capacity. I believe, however, that if

such an institution were created, the Government would continue to coöperate in the future as in the past.

"I therefore suggest the idea of a privately endowed National Earthquake Institute as one of the goals of the indefinite future of seismology."

When the time comes to attack this problem, it is the opinion of those who are represented by the type of membership of The Franklin Institute which will settle the issue.

Clouds Measure Speed of the Wind for Aviators.—(U. S. Department of Agriculture—Clip Sheet No. 675.) Men have discovered a new use for the clouds that float in the blue—as wind gages. Aviators always like to know the speed of the wind at various levels. A cloud travels with the wind, and makes visible the speed of the wind at a certain altitude.

The Weather Bureau of the United States Department of Agriculture has devised apparatus by which observers can determine how fast a cloud is moving. They sight the clouds in a black mirror mounted in a frame graduated in degrees. By observing the movement of the image of a cloud as reflected by the mirror for a certain period of time, they get one factor for a computation.

The other factor is the height of the cloud above the earth. The observer determines the distance from the earth to the cloud by releasing a standard "ceiling" balloon, and watching it until it disappears into a cloud. These balloons are inflated to a certain pressure, and the observer knows how rapidly such a balloon rises. By timing it from the moment of release until it enters the cloud it is easy to make a close estimate of the height of the balloon. With this as a second factor the observer computes the rate at which the cloud is moving, and can tell the pilot whether he will fly against a headwind or have the benefit of a tailwind.

Frequently it is possible to inform the pilot that he will encounter a favorable wind at about a certain altitude, but will find less favorable flying conditions at other altitudes.

R.

COMPARISON OF SOURCES FOR ZINC RESONANCE RADIATION.

BY

ALLAN C. G. MITCHELL,

Bartol Research Fellow.

INTRODUCTION.

BARTOL RESEARCH FOUNDATION
Communication No. 57.

In doing work on resonance radiation a source of light giving a strong resonance line with unreversed core is necessary. In the last few years a number of experiments have been made on the resonance radiation of mercury, and some on that of sodium, cadmium, zinc, and thallium. By far the greatest amount of work has been done on mercury since its resonance line is strong and lies in an accessible region of the spectrum (λ 2537 Å.), and since a good source of radiation is available, namely, the water cooled quartz mercury arc. With cadmium and zinc, the work is more difficult because the long wave-length resonance lines are weaker (Cd λ 3261 Å., and Zn λ 3075 Å.), and a good unreversed source is harder to obtain. Numerous sources for zinc and cadmium resonance radiation have been used by various investigators but, so far as the writer is aware, no comparison of these sources has been given nor have they been compared with the results that can be obtained with mercury resonance radiation using a good water cooled and magnetically deflected mercury arc as a source.

In connection with some work on the polarization of stepwise radiation in zinc, the writer has had occasion to try out several different sources for zinc resonance radiation; namely, a high potential discharge tube in helium and zinc described by Ellett,[1] a hollow cathode discharge tube of the Schüler type,[2] and an arc with a hot cathode. The results obtained are strictly qualitative but is believed that they will be helpful

[1] A. Ellett, *Journ. Opt. Soc.*, **10**, 427 (1925).
[2] H. Schüler, *ZS. f. Phys.*, **35**, 323 (1926); **59**, 149 (1930).

to those who are looking for a source for resonance work with the higher melting point metals.

TYPES OF SOURCES AVAILABLE.

Of the various types of arc in use other than those to be described in this paper, the one that has been used most is built with the same design as the Cooper Hewitt vertical quartz mercury arc with tungsten anode and a puddle of the desired metal as cathode. The main difficulty with these arcs is that metals such as cadmium and zinc attack quartz and usually crack it on solidifying after the arc is turned off. In the case of cadmium, F. Bates [3] found that a small amount of gallium prevented cracking and that a good arc could be made with the help of this metal. J. R. Bates [4] suggested the use of an alloy of cadmium and tin instead of gallium, which is expensive, and found that this prevented cracking to a large extent. He experienced some difficulty, however, due to cracking of the quartz to pyrex seals through which the tungsten connecting rod was led in to make contact with the metal puddle. In the arcs Bates used, this seal was at the bottom of the arc so that the molten cadmium tin alloy came in contact with it. Later, he packed the seal with ground up silica and found this to be effective in preventing cracking. The writer has used an arc of this type modified in such a way that the cadmium tin alloy was contained in a large bulb at the bottom of the arc with the quartz to pyrex seal carrying the lead in rod placed in a nearly vertical position on the side of the bulb. In this way no molten metal ever touched the seal and cracking was prevented. The difficulty with this type of arc is that both cadmium and zinc attack quartz forming a brown deposit on the walls so that after running a short time considerable light is lost. In the writer's experience this type of arc is not as effective in producing resonance radiation as those to be described in this paper.

Another very effective source of resonance radiation is an arc described by Cario and Lochte-Holtgreven [5] which is essentially a direct current arc in helium and the metal whose

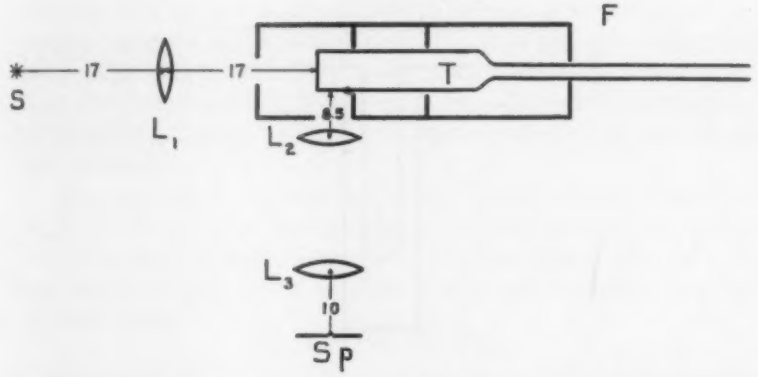
[3] F. Bates, Bureau Stand. Sci. Papers No. 371 (1920).
[4] J. R. Bates, *Journ. Amer. Chem. Soc.*, **50**, 771 (1928).
[5] G. Cario and W. Lochte-Holtgreven, *ZS. f. Phys.*, **42**, 22 (1927).

resonance radiation is to be studied, and in which certain precautions are taken to prevent the metal from reaching the window from which the radiation is taken off.

DESCRIPTION OF EXPERIMENTS.

Figure 1 is a diagram of the experimental arrangement used in the experiments. Light from the source, S, was focused on a quartz resonance tube, T, by means of a quartz lens, L_1, and the resonance radiation was taken off at right angles from the tube and focused on the slit of a small quartz spectrograph, Sp, by means of the quartz lenses L_2 and L_3.

Fig. 1.



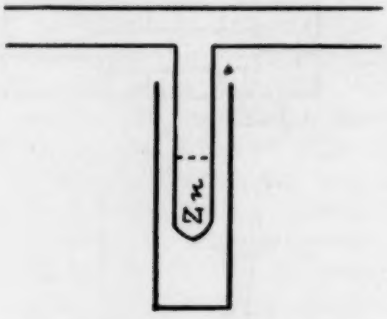
The resonance tube was placed in a furnace consisting of three compartments, the temperature of each compartment being controlled by independent heating units, and measured by thermocouples. A side tube, containing zinc and connected to the resonance tube, was placed in the center compartment which was kept about 100° C. cooler than the outside compartments to avoid condensation of the zinc vapor on the windows of the tube. The furnace was equipped with quartz windows for letting in and taking off the light. The resonance tube was always connected to the pumps through a liquid air trap. Throughout the experiments, the arrangement of apparatus remained the same.[6]

[6] In some experiments parts of the outside of the resonance tube were painted black to cut down scattered light in the visible region. With the temperatures

A. The High Potential Discharge Tube.

The high potential discharge tube in this experiment was similar to that described by Ellett (l. c.). It consisted of a quartz tube about 40 cm. long and 1 cm. diameter connected by graded seals to pyrex tubing at the ends. The electrodes, aluminum cylinders 15 cm. long and 3 cm. in diameter, were cooled by a pyrex water jacket. Helium or hydrogen could be admitted to the tube at any desired pressure but no provision was made for flowing the gases continuously through the tube. To the center of the quartz tube was sealed a side tube, also of quartz, containing pure zinc (see Fig. 2), which

Fig. 2.



could be heated by means of a small furnace; the remainder of the tube was not in a furnace. The tube was operated on 4600 volts from a 5 kva. transformer, and the current through it was controlled by a resistance in the primary circuit and could be varied from 0.3 to 1 amp.

To operate the discharge tube [7] a few millimeters of hydrogen or helium (the pressure is not critical) was admitted and the current turned on. The furnace on the side tube was then heated until the blue color of the zinc spectrum could

used, 400° C. to 500° C., it was difficult to find a paint that would not burn off. Finally a thin paste of copper oxide and water was made up and painted on the tube. This was found very effective for cutting down scattered light and did not burn off. In the experiments referred to in this paper all plates showed only the resonance line λ 3075 Å. of zinc.

[7] The writer is indebted to Professor Ellett for advice concerning the operation of the tube.

be seen about 5 cm. on either side of and extending down into the side tube. A temperature of from 450° to 470° C., corresponding to a vapor pressure of zinc of about 0.7 mm. was found to give the best results. A better yield of resonance radiation occurred with helium rather than hydrogen in the discharge, so that in all experiments quoted hereafter it is to be understood that helium was used. When the discharge was running correctly the whole tube showed the pure helium spectrum with the exception of about 10 cm. in the center, which showed practically nothing but zinc lines. If too much zinc distilled into the discharge, the whole tube turned blue; under these conditions the resonance line was reversed and no resonance radiation was found. In order to keep zinc from condensing on the walls of the tube just above the side tube a small gas-air flame was directed to this point. This greatly increased the intensity of resonance radiation obtained. It was further found that the best results were obtained with currents of about 0.5 amp., higher currents leading to some self reversal.

Reproducible results were not easily obtained with this type of arc, due to the difficulty of keeping the zinc pressure and helium pressure constant. Helium was found to "clean up" on the electrodes so that it had to be replenished from time to time.

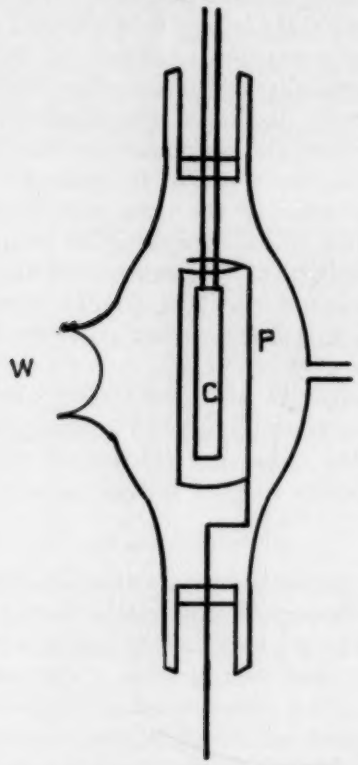
B. The Hot Cathode Arc.

Another type of source used was the hot cathode arc shown in Fig. 3. *C* is an equipotential, oxide coated cathode 0.5 cm. in diameter and 4 cm. long. *P* is a semi-cylindrical nickel plate 5 cm. long and of 1 cm. radius. The two were enclosed in a pyrex bulb with a pyrex window *W*, blown thin so as to transmit radiation of wave-length 3000 Å. with full intensity. Zinc was distilled into the bulb through a side tube and provisions were made for connecting the bulb to the pumps and helium supply. The whole arc was mounted in a furnace with a quartz window.

The arc was pumped out and a small amount of helium admitted. The cathode, drawing 9 amps. from a 10 volt circuit, was turned on and 110 volts D.C., connected through suitable resistances, was applied between cathode and plate. A helium discharge, drawing from 2 to 5 amps., then filled

the whole bulb. The furnace was next heated up gradually and at 330° C. zinc lines began to appear. At 370° C., furnace temperature, the arc constricted so that it was brightest between cathode and plate but still gave some glow throughout the body of the bulb. The helium was then

Fig. 3.



pumped out and a very bright zinc spectrum was seen. The arc drew about 5 amps. Under these conditions pictures of resonance radiation were taken.

This type of arc is very steady and controllable. It had the disadvantage, however, that nickel, which sputtered from the plate, covered the window to such an extent that the intensity of the light leaving the arc was cut down. It would probably be better to use a zinc plate, as suggested by Wali

Mohammad and Sharma [8] and not to heat the arc in a furnace. This type of arc has the advantage of being simple, easy to construct and run, and gives very good resonance radiation, as will be shown when a comparison between the different sources is made in a later section of this paper.

C. The Hollow Cathode Discharge Tube.

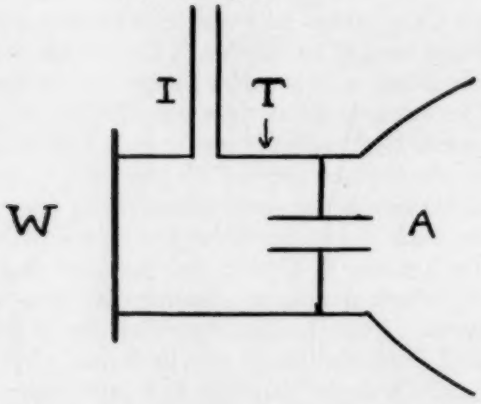
This type of discharge tube, described by Schüler (l. c.) and used extensively for the study of hyperfine structures, was selected because it gives narrow, unreversed lines of great brilliancy. The tube used in this investigation was of the usual form, consisting of a nickel cylinder 10 cm. long and 1 cm. in diameter, as cathode, which was partially filled with zinc. The cylinder was fastened to a nickel lead and support through small nickel wires to avoid conduction away of heat. Two nickel rings served as anodes. The whole was mounted in a pyrex tube fitted with a water jacket for cooling purposes. The distinctive feature of the tube was the use of a window of the Cario-Lochte-Holtgreven type (l. c.); Fig. 4 gives a diagram of this window as applied to the tube. *A* is a short tube 1 cm. in diameter, the same diameter as the cathode and placed in line with it, at the entrance to the tube. This is surrounded by a tube, *T*, 3.5 cm. in diameter and 3 cm. long to the end of which a quartz window, *W*, was fastened by means of picein. Pure helium, purified by a Misch metal arc and passed over chabazite ore in liquid air,[9] was led in through a capillary leak, through the inlet tube *I*, and out at the rear of the tube. The helium was circulated continuously through the tube and purifying system by means of a mercury vapor pump; the pressure in the tube, read on a McLeod gauge, was regulated by the speed of the pump. The Cario-Lochte-Holtgreven window was found very effective in keeping zinc from condensing on the front window. The tube has been run for several weeks and although zinc has distilled over most of the tube, none has passed the constriction leading to the quartz window.

[8] Wali Mohammad and Sharma, *Phil. Mag.*, 10, 916 (1930).

[9] The writer is indebted to Professor A. G. Shenstone, of Princeton University, for supplying him with the chabazite ore and for helpful suggestions as to the design of the tube.

The tube was operated in the following way. With helium, at 3 to 5 mm. pressure, circulating through the system, a potential of 750 volts D.C. was applied between anode and cathode through suitable resistances. When the discharge first struck in the cathode it was, of course, white and showed only helium lines. As the pressure was lowered and the current increased, the color of the cathode glow changed to red and showed mostly zinc lines, the helium lines becoming weak. On first operating the tube the pressure was lowered to less than 1 mm. and the current increased to about 200 milliamps in order to heat up the cathode and the zinc to out-gas them. After running some time a pure spectrum was obtained.

Fig. 4.



Pictures of resonance radiation were taken under many different conditions of pressure, current and voltage in the tube, and it was found that the best results were obtained when the helium pressure was about 3.5 mm., the current 120 milliamps, and with 750 volts supplied from the generator. Higher currents gave less resonance radiation, probably due to some self-reversal; while lower currents gave less also, due to fewer atoms being excited. Lower helium pressures were also not as effective in producing a strong unreversed zinc resonance line as were the higher pressures.

On the whole, this type of tube was very successful as a source. It was steady, and reproducible results could be obtained. Since all the light came from a small area in the

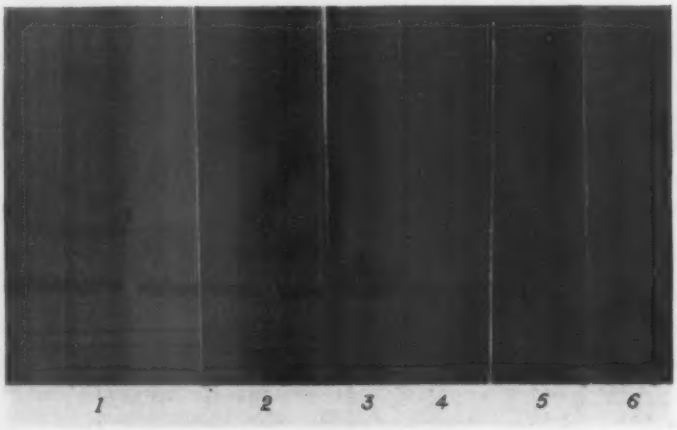
tube, the opening of the cathode cylinder, this could be focused in a small spot on the window of the resonance tube, giving rise to no scattered light due to internal reflection in the quartz. It was found unnecessary to coat the tube with black paint when this source was used.

COMPARISON OF THE SOURCES FOR PRODUCTION OF RESONANCE RADIATION.

In making pictures of the resonance radiation various temperatures of the resonance tube ranging from 260° C. (v. p. Zn $\approx 2 \times 10^{-4}$ mm.) to 440° C. (v. p. Zn $\approx$ 0.28 mm.) were used. These temperatures are those of the central compartment of the furnace which controlled the vapor pressure of the znc, and the temperatures of the outside compartments were always hotter than this to prevent condensation. It was found that better results were obtained with higher temperatures. It is obvious that this should be so since the amount of light absorbed and reemitted as resonance radiation is proportional to the number of zinc atoms present, and hence to the vapor pressure.

The results of the comparison of the different sources is shown in Fig. 5, which gives densitometer curves of the line λ 3075 Å. taken in resonance with different sources and tem-

Fig. 5.



1. Discharge tube; resonance tube at 320° C.
2. Arc; resonance tube at 330° C.
3. Hollow cathode; resonance tube at 330° C.
4. Discharge tube; resonance tube at 360° C.
5. Hollow cathode; resonance tube at 360° C.
6. Hollow cathode; resonance tube at 400° C.

peratures of resonance tube as shown. The plates were not calibrated with intensity marks, but were all developed for the same length of time (3 minutes) with the same type of developer (Eastman Special Developer; Eastman Speedway Plates used). The exposure times of the plates were 30 seconds. The densitometer was linear with the light intensity over the range used.

Since the plates were not calibrated for light intensity the results can be taken as only qualitative. They show, however, that the high potential discharge tube gave better results than the hollow cathode tube; and that the hot cathode arc was about as good as the high potential discharge tube. With all sources very weak traces of the resonance line could be seen on 5 seconds exposure. A comparison using a Cooper-Hewitt, water cooled and magnetically deflected quartz mercury arc and mercury vapor pressure corresponding to that at room temperature (0.0013 mm.) shows that a 5 second exposure for mercury resonance radiation was slightly more intense than a 1 minute exposure for zinc.

GENERAL REMARKS.

The zinc resonance line λ 3075 Å. ($1^1S_0 - 2^3P_1$) is an intercombination line and is rather weak compared to the same line in mercury. The mean life of the 2^3P_1 state of zinc has been shown to be 3.2×10^{-5} sec., while that of the corresponding state in mercury is 1.3×10^{-7} sec. The relative total absorption for the resonance line for various vapor pressures of either gas can be obtained in the following way. Let α_ν be the absorption coefficient for frequency ν, then the total absorption across the line is related to the Einstein absorption probability B_{12}, by

$$\int^{\infty} \alpha_\nu d\nu = \frac{h\nu_0 N}{c} B_{12},$$

where ν_0 is the frequency of the center of the resonance line, N the number of absorbing atoms per c.c. present, and h is Planck's constant. B_{12} is related to A_{21}, the spontaneous emission probability, by

$$\frac{A_{21}}{B_{12}} = \frac{8\pi h\nu^3 g_1}{c^3 g_2},$$

where g_1 and g_2 are the *a priori* probabilities of states 1 and 2, respectively. But A_{21} is related to the mean life, τ, by

$$A_{21} = \frac{1}{\tau}.$$

A short calculation shows that the ratios of the total absorption of the resonance line of zinc (λ 3075) to that of mercury (λ 2537) is

$$\frac{\left(\int_0^\infty \alpha_\nu d\nu\right)_{Zn}}{\left(\int_0^\infty \alpha_\nu d\nu\right)_{Hg}} = \frac{N_{Zn}}{N_{Hg}} \cdot \frac{(\lambda_0^2)_{Zn}}{(\lambda_0^2)_{Hg}} \cdot \frac{\tau_{Hg}}{\tau_{Zn}}.$$

Substituting the values for τ and λ_0 given above, one obtains, for the total absorption

$$\frac{\left(\int_0^\infty \alpha_\nu d\nu\right)_{Zn}}{\left(\int_0^\infty \alpha_\nu d\nu\right)_{Hg}} = \frac{N_{Zn}}{N_{Hg}} \cdot 4 \times 10^{-3}.$$

Thus it is seen that in order to get zinc resonance radiation of the same intensity as mercury resonance radiation at room temperature, the vapor pressure of zinc in the resonance tube must be 250 times that of mercury vapor at room temperature or 0.32 mm. (corresponding to a temperature of 450° C.), the intensity of the exciting line of zinc must equal that of mercury, and the resonance radiation must be observed from the same distance behind the entrance window of the resonance tube.

The main difficulty in obtaining as large an amount of zinc resonance radiation using a zinc arc compared to mercury resonance radiation using a mercury arc is that the zinc resonance line in the arc is much weaker than the mercury mercury resonance line in the mercury arc, since the Einstein emission probability for the mercury line is about three hundred times greater than for the zinc resonance line. The fact that such good yields of zinc resonance radiation were obtained indicates that the source must have been practically free from self reversal.

Any of the sources tried is good enough for work on the properties of the λ 3075 Å. resonance line of zinc, such as quenching and polarization; but none was strong enough for the study of the polarization of "stepwise radiation." [10] The most convenient and economical source would seem to be the hot cathode arc.

In conclusion the writer wishes to thank Mr. Austin G. Nester for blowing the glass for the arcs used in this experiment.

[10] The fact that P. Bender (*Phys. Rev.*, **36**, 1535 (1930)) was able to obtain stepwise radiation in cadmium and zinc was due to his being able to surround his resonance tube with the high potential discharge tube. Such a procedure is not possible in studying the polarization of stepwise radiation, since in this case the exciting beam must be oriented in a definite direction to that at which the resonance radiation is observed.

THE ISOTOPES OF LITHIUM, SODIUM, AND POTASSIUM.

BY

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Communication No. 55.

ABSTRACT.

Part I. *The relative abundance of the isotopes of lithium.* Magnetic analysis of the positive rays of lithium from a heated spodumene source shows no change with temperature in the relative abundance of Li^7 and Li^6. This is in agreement with Aston and Morand but at variance with the results of G. P. Thomson, Dempster, and the similar work of Hundley. A possible explanation of Hundley's and Dempster's results appears when the effects of space charge and the geometry of the tube are considered. In the present work the ion currents were not limited by space charge, and the ions of the isotopes of lithium when brought successively to the receiving slit described exactly the same path throughout; the resolving power of the apparatus was great enough to secure complete separation of the ion beams, and proper diaphragming eliminated background due to strays.

Part II. *Positive Ion Sources.* Ions of the alkali metals were produced from heated natural mineral silicates of the alkali metals. The technique of preparation and activation of these sources is described. The results of tests of the type and abundance of the emitted ions for five specific alkali metal ion sources are presented. Results are given of tests of barium and strontium positive ion sources.

Part III. *The Isotopes of Sodium and Potassium.* Sodium and potassium have been examined for the presence of small amounts of isotopes other than Na^{23}, and K^{39} and K^{41}. If Na^{21} or Na^{25} exist at all they are present to less than 1/3000 of the main isotope and Na^{22} cannot be present to an extent greater than 1/800 of Na^{23}.

From the analyses of potassium it is concluded that there is less than one part in 1500 of K^{43}, less than one part in 600 of K^{42}, and less than one part in 300 of K^{40}, in reference to K^{39} if they exist at all.

Part I. The Relative Abundance of the Isotopes of Lithium.

A. Introduction.

B. Conditions for determination of abundance ratios.

C. Description of apparatus.

a. Tube design.

b. Ion source.

D. Conditions for identical trajectories of ions of different e/m.

E. Limitation of current by space charge.

F. Measurement of ion currents.

G. Method of procedure and results.

H. Discussion of results.

Part II. Digression on Positive Ion Sources.
A. Ions of the alkali metals.
B. Positive ions of barium and strontium.

Part III. The Isotopes of Sodium and Potassium.
A. Sodium.
B. Potassium.

I. THE RELATIVE ABUNDANCE OF THE ISOTOPES OF LITHIUM.

Introduction.

The relative abundance of the isotopes of lithium has been the subject of several investigations in recent years. The results of three of these researches are wholly at variance with the accepted theoretical concepts of the behavior of isotopes. The present work was undertaken to measure the ratio under carefully controlled experimental conditions. The wide variations of the relative abundance obtained in previous investigations might be spurious or might arise from some hitherto unsuspected coupling of one kind or another existing between the different lithium nuclei and their respective external structure. Such a condition might conceivably promote changes in the measured relative abundance of the isotopes under varying physical conditions at the source of the lithium ions.

Studies of the relative abundance of the isotopes of lithium have been made by A. J. Dempster,[1] G. P. Thomson,[2] F. W. Aston,[3] M. Morand,[4] and J. L. Hundley.[5] Dempster ionized lithium vapor by electron impact and obtained ratios of Li^7 to Li^6 varying from 37 to 1 to 4.8 to 1, after separating the positive rays by his well known method of magnetic analysis; the ion currents were measured electrically. Thomson utilized an anode ray source [6] and separated the isotopes by the parabola method, recording the ions on a photographic plate. The relative abundance of the lithium isotopes was found to vary over a considerable range when the discharge conditions were altered; no precise figures were obtained owing to the

[1] A. J. Dempster, *Phys. Rev.*, **18**, 420 (1921).
[2] G. P. Thomson, *Phil. Mag.*, **42**, 857 (1921).
[3] F. W. Aston, *Phil. Mag.*, **47**, 385 (1924).
[4] M. Morand, *Comptes Rendus*, **182**, 460 (1926), *Ann. de Physique*, **7**, 164 (1927).
[5] J. L. Hundley, *Phys. Rev.*, **30**, 864 (1927).
[6] Gehrke and Reichenheim, *Verh. d. Phys. Gesell.*, **9**, 76, 200 (1907).

difficulty of calibrating the photographic plate. Aston, using his mass-spectrograph with accelerated anode rays, made a large number of records of the isotopes of lithium under widely varied conditions and found no change in the intensity ratio of the isotopes. Morand obtained lithium ions from heated salts [7] of the metal. The isotopes were separated by the Dempster magnetic focussing method of analysis. With increasing currents the ratio of Li^7 to Li^6 decreased. Morand demonstrated that this effect was due to the overlapping of the ion beams at high current densities. The true abundance ratio was constant. In Hundley's work the ions were produced thermally from four different lithium compounds. The method of investigation was similar to that used by Dempster with the addition of improved current measuring methods. The abundance ratios obtained varied from 7.5 to 1 to 130 to 1 for different sources and temperatures. As the present work is closely related to Hundley's work, it will be compared with it more fully later. The present paper has been written to describe experiments performed under carefully controlled conditions which give evidence that even under varying conditions at the source the ratio of abundance of the lithium isotopes is sensibly constant and previous findings of variations in this ratio are a result of the experimental conditions.

Conditions for Correct Measurements of Abundance Ratios.

It is significant that in Aston's work the paths described by the two isotopes of lithium are the same until the positive rays are introduced into the magnetic field for separation and analysis. In Morand's research large radii of curvature were used, allowing practically identical paths for Li^7 and Li^6 at the source. High accelerating fields insured that the ion currents were not limited by space charge. As will be shown later, two essential criteria for the correct determination of the abundance ratio of the isotopes of an element are, (1) the ion currents should not be space charge limited, (2) the ions of the isotopes should follow identical paths up to the analyzing apparatus. Complying with these requirements, Aston and Morand found no change in the ratio Li^7/Li^6 under varying conditions at the source. Obviously, if two ion beams repre-

[7] Gehrke and Reichenheim, *Verh. d. Phys. Gesell.*, **8**, 559 (1906).

senting two isotopes of different e/m are describing different paths before reaching a final collimating slit at the entrance to an analyzing chamber, a selective process will take place sooner than is desired and the abundance ratio will be varied depending upon which isotope beam is favored at the slit. Two ion beams of equal energy but different e/m will follow different paths at the source if a stray magnetic field is present and the proper precautions are not taken to insure identical trajectories in this field.

If the ion current is limited by space charge with hot anode sources a region of minimum potential exists outside the filament and this region of minimum potential is far enough removed from the anode to alter appreciably the effective separation of the anode and cathode, and to change the field distribution in the ordinary arrangement of the Dempster type mass-spectrograph. As soon as space charge sets in, the phenomena at the source increase greatly in complexity. Besides the dependence of the emission on the voltage, on the separation of anodes and cathodes, and on the mass of the ions, the total ion current also depends on the relative masses [8] of all the ions present and on the relative abundance of those ions.

For measurements of the absolute abundance ratio of two isotopes other and more rigid requirements are introduced. In particular, the mechanism of emission of the ions must be known. In the present work, the interest is centered on the way the abundance ratio changes with temperature at the source. A knowledge of the true absolute ratio of abundance is not essential for examination of the phenomena treated in this investigation.

Description of Apparatus.

a. Tube Design.

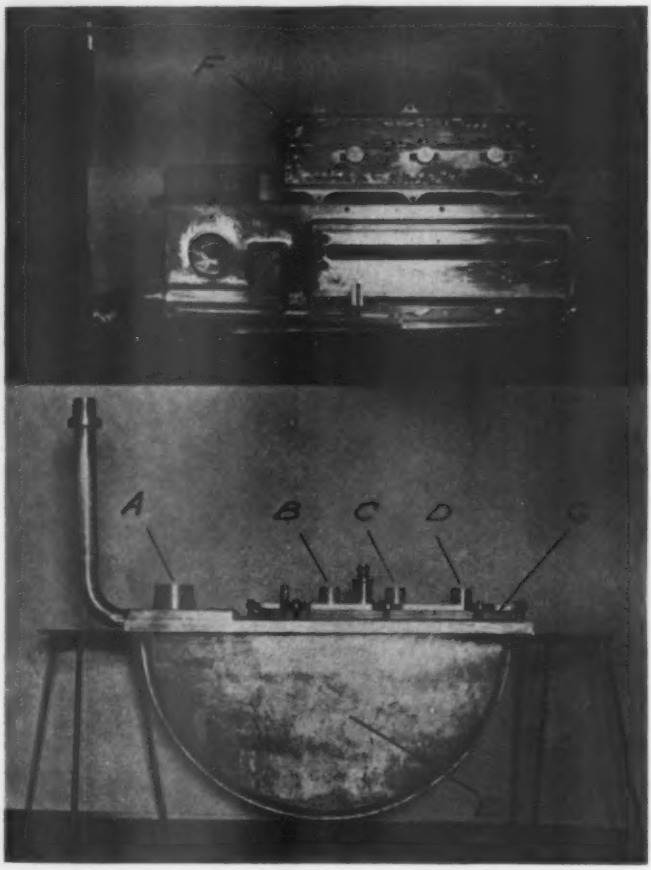
Figure 1 illustrates the tube used for the magnetic analysis of the isotopes of lithium. The general method of procedure follows that first introduced by Dempster [9] for the analysis of positive rays. The ion source was located at A and the receiving Faraday cylinder which was used for this investigation was at B. The slit width S at the source was 0.03 cm. The di-

[8] H. A. Barton, *Phys. Rev.*, **26**, 360 (1925).

[9] A. J. Dempster, *Phys. Rev.*, **11**, 316 (1918).

mensions of the receiving slit were 0.033 × 0.5 cm. The radius of curvature of the ion beam brought to a focus at B was $R = 9.2$ cm., giving a theoretical resolving power ($M/\Delta M = 2R/2S$) of 279 for a non-divergent beam at the

FIG. 1.



Plan and elevation of mass spectrograph.

source. If the half angle of divergence of the beam is θ then the width of the refocussed beam at B is approximately $2R(1 - \cos\theta)$ and a simple calculation shows that for a value of θ of 4° the resolving power would be reduced to 208.

The mass spectrograph was built around two soft steel plates, each 1.27 cm. thick, semicircular in shape and of 20 cm. radius. The plates were separated 1.59 cm. by brass spacers. These plates were secured at the top to the brass cover and the assembled plates were surrounded by two spun copper cans E of 0.039 cm. thickness which were soldered, as shown in Fig. 1, to the brass cover plate and to each other on their common periphery. The clearance between this assembly and the poles of the magnet was only 0.013 cm. The large cover plate F was required for other work to allow the use of 25 × 2.5 cm. photographic plates. The plate moving mechanism, plate holder, and diaphragm can be located easily in the photographs. The top cover plate was made vacuum tight by painting the fillet at G with Glyptal lacquer. This soon drys and under the best conditions the pressure in the tube would only rise to 4 or 5 baryes in 12 hours with the pumps shut off. The diffusion pumps were, of course, running continuously while readings were taken, one pump for the focussing chamber and another for the source chamber. The inside walls of the steel poles were etched slightly to roughen the surface and cut down specular reflection of ions from the walls. Radially spaced brass strips also acted as collimators preventing reflection of ions from the side walls and allowing only those ions to reach B which were properly directed. These strips interfered only with lateral motion of the ions and did not act as baffles for positive rays of radii greater or less than 9.2 cm. The large electromagnet [10] will not be described fully at this time. The semicircular pole pieces were 40 cm. in diameter.

b. Ion Source.

The lithium ions were produced thermally from heated spodumene, the source which gave the greatest ratios of Li^7/Li^6 in Hundley's work.

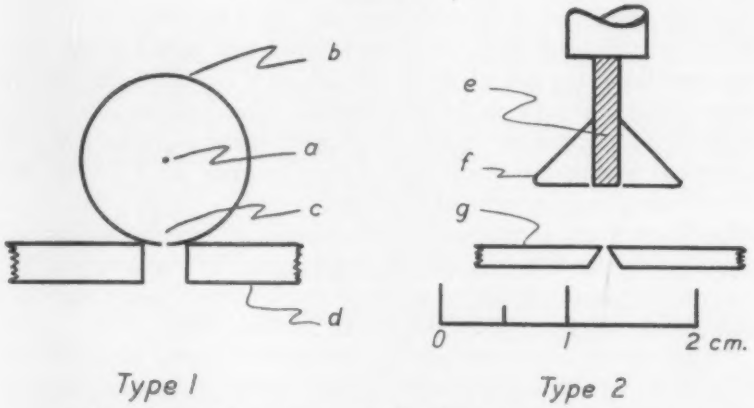
Two types of ion sources were used, and are shown diagrammatically in Fig. 2. The type 1 source is similar to that used by K. Cole [11] for electrons. In Fig. 2, a is a platinum

[10] This magnet is illustrated in the JOURNAL OF THE FRANKLIN INSTITUTE, 210, 753 (1930).

[11] K. Cole, *Phys. Rev.*, 28, 787 (1926).

filament, diameter 0.038 cm. which may be coated with any ion emitting substance, *b* is a copper cylinder surrounding it approximately 1.27 cm. in diameter, *c* is a slit 0.03 × 0.5 cm., and *d* is a copper base which is located in the apparatus at *A*, Fig. 1, by dowel pins. The filament was supported by two insulated pillars. Expansion due to heating is taken up by a 0.063 cm. tungsten spring. This type of source was excellent for hot anode purposes and allowed a resolving power of 200 without any complications in setting it up. Although this type of source gave consistent values for Li^7/Li^6 it had to be abandoned as the gradient at the surface was sufficient to tear

FIG. 2.



Arrangement of filaments and slits for hot anode type positive ion sources.

off the coating. In any case the constancy of emission was not as great as desired, i.e. absolute constancy continuously for at least 30 minutes.* This type of source, however, is excellent for the study of ion emission characteristics of the filament proper. Steady emission was secured for Th, ThO and W ions from a thoriated tungsten filament.

* A Compton electrometer was used for ion current measurements as it appeared to be the most satisfactory instrument for this particular research. When used at the necessary high voltage sensitivity the electrometer period was so great that all the readings for a curve similar to Fig. 3 required twenty or thirty minutes. Steadiness of the ion source is important regardless of the method of current measurement.

In Fig. 2 type 2 is shown the source finally adopted. e is a strip of platinum about 4 cm. long, approximately 0.2 cm. wide and 0.0076 cm. thick. f is a molybdenum guard "ring" to correct the field distribution around the filament and g is the source slit system with beveled jaws 0.03 cm. apart and 0.8 cm. long. e and f were supported on leads in a large grind which made the process of alignment difficult, but once correctly assembled it was satisfactory. With this type of source the lithium ion current could be maintained constant for hours. The separation of f and g was approximately 0.5 cm. The high voltage connection to the platinum strip was made to the center of a 60 ohm resistance shunted across the strip, acting in effect as a connection to the mid-point of the filament and thereby minimizing the effect of the potential drop across the filament. A long series of experiments was made using grids intermediate between the filament and slit but the results were unsatisfactory as fictitious peaks would occur and it was practically impossible to insure that different isotopes followed identical paths between the filament, grid, and source slit when brought to a focus at the receiving slit. However, in the experiments on sodium and potassium an intermediate slit, not a grid, was used which often increased the resolution, but by proper manipulation of the accelerating fields did not change the abundance ratio of the K isotopes.

No magnetic shielding was used at the source as under the conditions of the experiment the deflection of the ion beams at the source is slight and can be compensated easily by proper adjustment of the filament.

Conditions for Identical Trajectories of Ions of Different e/m.

For the ions of mass M_1 to follow the identical path of the ions of mass M_2 in the analysing chamber, the product MV should be constant, where M is the mass of the isotopes and V is the potential difference between the filament and source slit.

The equation for the radius of curvature of the ion beam in the spectrograph is the familiar equation $HR = 143.97\sqrt{MV}$, where R is in cm., H the field intensity in gauss, M is the mass of the ions in atomic weight units, and V is in volts. As R is fixed and H is maintained constant, the condition for two isotopes of masses M_1 and M_2 to follow the same path in the

focussing field is that $M_1V_1 = M_2V_2$. In the present instance V_1 was 600 volts for Li^7 and 700 volts for Li^6.

For the same path between the filament and the source slit for different isotopes, M_1V_1 must again equal M_2V_2. For the type 2 source the path of the ions is approximately cycloidal. If H is uniform in this region the deflection of the ion beam from the line of centers of the filament and slit is $Y = 4.63 \times 10^{-3}HX^2/\sqrt{VM}$ cm., where H is the field intensity in gauss, X is the distance between the filament and slit in cm., and V and M are expressed in volts and atomic weight units. Under the assumption of a uniform field equal to the focussing field of the value used in these determinations, the maximum deflection of the ion beam would be only 0.009 cm. For a magnetic field which is varying in intensity between the slit and the filament, the same criterion appears for the condition of identical paths for different isotopes, i.e. $M_1V_1 = M_2V_2$.* The above equation for Y gives the deflection of the ion beam from a straight line for the worst conditions which can arise. The full importance of the necessity for identical paths will be developed in the discussion of results later.

Limitation of Current by Space Charge.

The maximum ion current as limited by space charge [12] is given by the equation $i = 5.45 \times 10^{-8}\ V^{3/2}/X^2\sqrt{M}$ amp/cm². The maximum current density under the conditions of experiment for $V = 600$, $M = 7$, $X = 0.5$, is then $i = 1.21 \times 10^{-3}$ amp/cm². The actual maximum current density in the ion beam was 1.85×10^{-6} amp/cm²., indicating that the current was temperature limited and not space charge limited. An independent check of whether the current was space charge limited was made by reducing the magnetic field and then bringing the Li^7 ion to focus at a lower voltage V. The ion current was within five per cent. of the ion current at 600 volts and supported the contention that the current was not space charge limited even at the highest current density utilized.

* The condition for identical paths at constant magnetic field intensity, $M_1V_1 = M_2V_2$, has been shown by Professor Swann to satisfy the general case of non-uniform electric and magnetic field distribution.

[12] I. Langmuir, *Phys. Rev.*, **2**. 450 (1913).

The space charge equation for positive ions has been checked by Killian.[13]

Measurement of Ion Currents.

The ion currents received by the Faraday collector at *B*, Fig. 1, were measured by a null method. Currents were measured by a Compton electrometer adjusted for a sensitivity of 12,500 mm. per volt. The voltage drop across one of four resistances was compensated by an equal and opposite potential applied from a potentiometer. With the usual steady deflection method the resistance is connected between one pair of quadrants and ground. With the present arrangement, the ground end of the resistance was connected to the negative terminal of the E.M.F. posts of an L. & N. potentiometer, and the positive E.M.F. terminal was earthed. This is a variation of the null method used with so much success by Compton and Thomas.[14] With this arrangement a linear current scale was procured regardless of the electrometer adjustment proper. The accuracy of measurement for large currents was increased greatly over the direct deflection method which is usually limited to a full scale deflection of 400 mm. With the null method, measurements were made with the highest practicable resistance and the equivalent steady deflection was about 1300 mm. for the medium current set of measurements of the Li^7 beam and 4600 mm. for Li^7 in the third (high current) set of measurements of the abundace ratio (see below). In determining the relative abundance of the isotopes only one resistance was used during the comparison of the respective ion currents of the isotopes in order to eliminate the possibility of two resistances changing in value with respect to each other.

Method of Procedure and Results.

The method of examination of the relative abundance of the isotopes of lithium was to bring the beams of ions successively to the receiving slit by changing the accelerating voltage, Li^7 appearing at 600 volts and Li^6 appearing at 700 volts approximately. Minute changes in the applied voltage could be made which was necessary to insure that the peak current was being measured, the sharpness of the peaks requiring great

[13] T. J. Killian, *Phys. Rev.*, **27**, 578 (1926).

[14] K. T. Compton and C. H. Thomas, *Phys. Rev.*, **28**, 607, 1926.

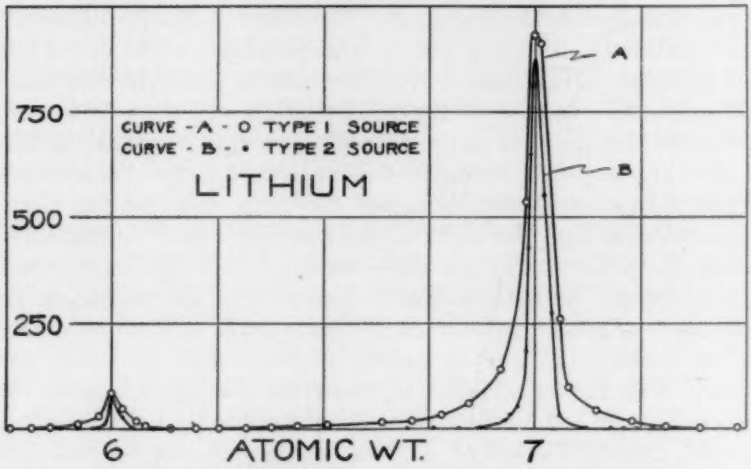
care in locating the true maximum. Readings of the Li^7 and Li^6 current were taken alternately and as rapidly as consistent with accuracy until five determinations had been made of each, a comparison of the first and last readings giving a check on the constancy of the source. In a separate series of experiments with just the Li^7 ion current, all factors influencing the ion emission were kept constant except the voltage gradient at the source. It was found that the ion current increased slightly with increased field intensity. No claim is made, however, that the effect observed was a true Schottky effect. At the low field intensities used it is more probable that the increased ion emission was due to the contribution of ions which were emitted from pockets and valleys in the rough surface of the coated anode. The limitation of current by the "local space charge" in these cavities would be decreased by increased "penetration" of the electric field at increased voltages between the anode and cathode. As a result of the dependence of ion current on field intensity the ratio Li^7/Li^6 as measured was lower than the ratio of abundance of the ions at 600 volts or 700 volts. Li^7 was measured at 600 volts and Li^6 at 700 volts. The Li^6 ion current at 700 volts was greater than the Li^6 current existing when the determination of Li^7 was made at 600 volts. Therefore, the ratios determined are not the absolute values of Li^7/Li^6, the uncertain nature of the mechanism of emission of the ions also renders impossible an absolute determination of the abundance ratio at this time. These measurements show that the abundance ratio is sensibly constant over a considerable range in temperature of the source in sharp contrast to the results of Hundley. No corrections were necessary for the background and strays. Figure 3 shows the resolution and form of the peaks attained using the type 1 and type 2 source. The abundance ratios tabulated below were determined from the peak heights alone, and not by taking complete curves. In an analysing apparatus as used in this research, the peak height gives the most accurate measure of the ion beam current.

In investigating the effect of the background in the particular runs taken for the measurements of the relative intensities of Li^7 and Li^6, only the minimum background region near atomic weight 6.2 was investigated. The background due to Li^7

strays was less than 1/800 of the Li^6 peak current for the third (11.51 ± 0.31) determination of Li^7/Li^6 and theoretically should be less for lower ion current densities.

The first and most accurate measurements were made after all circuits had been allowed two hours to attain equilibrium. The filament heating current was 7 amperes. For this run the

FIG. 3.



The isotopes of lithium for type 1 and type 2 sources using heated spodumene. Ordinates, ion current measured in arbitrary units, abscissas, mass of ions in atomic weight units.

The Relative Abundance of the Isotopes of Lithium.

	Filament heating current in amperes.	Approx. temp. of source.	Li^7 ion current in amperes.	Abundance ratio Li^7/Li^6.
1	6	1270° K.	9.62×10^{-12}	10.75 ± 0.8
2	7	1370° K.	2.7×10^{-10}	11.28 ± 0.07
3	9.4	1580° K.	3.05×10^{-8}	11.51 ± .31

Li^7 current was 2.7×10^{-10} amperes and the ratio of Li^7/Li^6 was 11.28 ± 0.07. The heating current was then reduced to 6 amperes. This was the minimum current giving steady emission, a slight decrease in the filament heating current brought the emission to the region of sharp cut-off with no ion emission occurring. At 6 amperes the Li^6 ion current was only 22 mm. while using the highest resistance 2.1×10^9 ohms.

The abundance ratio was 10.75 ± 0.8 at a Li^7 current of 9.62 × 10^{-12} amperes. For the third series of data the heating current was 9.4 amperes giving a Li^7 current of 3.05 × 10^{-8} amperes and a ratio of Li^7/Li^6 of 11.51 ± 0.31.

The temperatures given in the table are only rough approximations, the location of the filament making an optical measurement of the temperature impracticable. The temperatures were calculated from the known currents after one point had been secured on the temperature versus current scale. This point was obtained by increasing the heating current slowly until the filament burnt out. Examination of the filament showed that it had actually fused at the center so that at 14.5 amperes the temperature of the midpoint was approximately 2000° K. The temperatures of the filament at other currents were then roughly calculated, in comparison to the current-temperature scale for tungsten, which was sufficiently accurate for the purpose at hand.

Discussion of Results.

The work reported here is presented as evidence that the isotopes of lithium maintain a constant ratio of abundance as a function of temperature, a result at variance with the similar work of Hundley.[5]

The temperature of the source was varied over a wider range than in Hundley's work where a Kunsman source was used which gave abundance ratios for Li^7/Li^6 varying from 171 : 1 to 60 : 1. For a spodumene source the ratio varied from 130 : 1 to 35 : 1.

The highest currents in the present work were 3170 times greater than the current for the lowest temperature at which readings were taken, this lowest temperature being just above the threshold for inception of ion emission from spodumene. The ion currents in Hundley's work were varied over a maximum range of 15 to 1 considering the Li^7 ion current only.

It will be remembered that in Dempster's and Hundley's work the ions from the source were brought to a first slit by an unaltered potential of 30 to 100 volts and then between the first and the final second slit the ions fell through the full accelerating potential which was varied as required to bring successive ion beams to a focus at the receiving slit. In both

Dempster's and Hundley's work the ion beams of the two isotopes of lithium could not have followed the same paths as the voltage applied between the source and first slit or grid was maintained constant throughout a run, $M_1V_1 \neq M_2V_2$ in this region. In the stray magnetic field at this point the Li^6 beam would be deflected more than the Li^7 beam. As has been pointed out previously, any separation of the isotope ion beams at the source will result in changes in the abundance ratio depending upon which ion beam is favored at the slit leading to the analyzing chamber.

It is important to note that Dempster's measurements of the relative abundance of isotopes of elements of higher atomic weight, notably magnesium, did not present any great variations.[15] The deflection of an ion beam at the source at constant voltage has been shown to be proportional to $1/\sqrt{M}$. The greatest difference in deflection of two ion beams would occur for lithium, as it is, in our present knowledge, the element with the greatest percentage difference in mass between its constituent isotopes and is the lightest element with two isotopes. The separation of the isotope ion beams for lithium, proportional to $1/\sqrt{6} - 1/\sqrt{7}$, while small, is greater than for any other known element. The same phenomena giving an anomalous behavior to lithium may have been present in the case of magnesium, but the greater mass of the magnesium isotopes and smaller relative mass-difference-range existing minimized the difference in paths at the source.

Besides this consideration in Dempster's work, there is a probability that penetration, beyond the first slit, of the accelerating field between the first and second slits may have altered the emission of electrons used for ionizing the source vapor. As different accelerating potentials are required to bring Li^6 and Li^7 to the receiving slit the percentage ionization of the metallic vapor would change as some function of the accelerating voltage. Under these conditions the relative abundance of two isotopes would appear to vary. In a later paper [16] Dempster took precautions to prevent any influence of the accelerating field on the source conditions and obtained splendid results for a number of different elements.

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[15] A. J. Dempster, *Phys. Rev.*, **18**, 422 (1921).

[16] A. J. Dempster, *Phys. Rev.*, **20**, 631 (1922).

The above considerations may contain the correct explanation of Dempster's early results with lithium, but the dependence of the abundance ratio on temperature was found by Hundley, involves supplementary considerations. Only a qualitative explanation can be suggested as not enough data are available to make actual quantitative calculations. As will be shown, the change in the relative abundance of Li^7 to Li^6 as a function of temperature, is believed to be due to the influence of space charge at the anode in conjunction with the effects of different paths given above. Two facts noted by Hundley point to the influence of space charge. (1) As the temperature of the source is increased the relative abundance of Li^6 increased and (2) at high temperatures *and* low grid potentials the ratio Li^7/Li^6 decreases.[17] At low temperatures and without the ion current being limited by space charge the dimensions of the source are, of course, defined by the dimensions of the platinum strip proper. As soon as space charge sets in the effective dimensions of the ion source are considerably greater than the physical dimensions of the filament. With space charge limitation of the ion current a region of minimum potential is produced which for all practical purposes is the boundary of the ion source and is at an appreciable distance from the filament as the following calculations will show. The nomenclature is the same as used in Langmuir's paper.[18] It is desired to calculate Xm, the distance from the source to the region of minimum potential under values of the physical entities involved, such as could have occurred in Hundley's work. $Xm = -\xi_1/2L$, where $-\xi_1$ is a number (always less than 2.56) and a function of η_1, $\eta_1 = \log i_0/i$ where i_0 is the saturation current and i is the actual ion current. $L = 2(\pi/2kT)^{3/4}m^{1/4}(ei)^{1/2}$ $L = 3 \times 10^6 T^{-3/4} i^{1/2} M^{1/4}$ where T is in degrees Kelvin, i in amperes per square cm., and M is in atomic weight units. For $i/i_0 = 1$, $i = 3.6 \times 10^{-8}$ or less, $\eta_1 = 0$, $-\xi_1 = 0$, $Xm = 0$, or the source is defined by the dimensions of the filament emitting the ions. For $i/i_0 = 0.1$, $i = 3.6 \times 10^{-8}$, $\eta_1 = 2{,}303$, $-\xi_1 = 2.094$, $T = 1200°$ K, $Xm = 2.29$ mm. In this second case in which the ion current is space charge limited the effective size of the

[17] Reference 5, page 867, Reference 5, page 869.

[18] I. Langmuir, *Phys. Rev.*, **21**, 428 (1923).

source is considerably greater than the dimensions of the filament proper. Therefore a large uniform emitting surface supplies ions to the space beyond Xm where the ions receive their energy in going to the first collimating slit of Hundley's apparatus. The sidewise deflection of the ion beams of Li^7 and Li^6 is less than if the current was not space charge limited. As has been shown, this deflection $Y = 4.63 \times 10^{-3} HX^2/\sqrt{VM}$. X is the distance from the collimating slit to Xm in the space charge case and is considerably less than the distance between the first collimating slit and the filament proper as occurs for $i/i_0 = 1$, i.e. where the current is not space charge limited. Now if Hundley was working in the region where space charge limitation of the ion current was just setting in, as the temperature of the source was increased the value of Xm would increase, X would decrease, resulting in a decrease in Y, and the ratio Li^7/Li^6 would change and approach a value in accord with the true abundance ratio. The details of the experimental procedure and dimensions of Hundley's apparatus are unfortunately lacking so that no quantitative analysis of his results may be made. As no anomalous behavior was found for the ratio Li^7/Li^6 in the present work in which care was taken to avoid the effects of space charge and different trajectories for the Li^7 and Li^6 ion beams it is believed that the results of Hundley were a direct consequence of the experimental arrangement used and do not demonstrate any effects requiring a modification of present ideas on the behavior of isotopes and emission of positive ions from heated salts. Certainly the suggestion of G. P. Thomson,[19] that the isotopes of lithium differ from each other as much as lithium differs from the other alkali metals, may be discarded.

The true relative abundance of Li^7 to Li^6 is 12.87/1 as calculated from Costa's [20] packing fraction data, corrected by Aston [21] and using the I.C.T. value for the atomic weight. Also included is the correction necessary to change from the $O^{16} = 16.000$ scale to the oxygen = 16.000 or chemical atomic weight scale.[22]

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[19] Reference 2, page 861.

[20] J. L. Costa, *Ann. de Physique*, **4**, 454 (1925).

[21] F. W. Aston, *Proc. Roy. Soc.*, **115A**, 509 (1927).

[22] S. M. Naudé, *Phys. Rev.*, **36**, 344 (1930).

II. DIGRESSION ON POSITIVE ION SOURCES.

Ions of the Alkali Metals.

The lithium ions were produced from powdered spodumene. A suspension was made in a solution of one part Zapon lacquer to twenty parts of amyl acetate. This suspension was painted on the filament. No advantage is gained by the use of thick coatings. Thin coatings were satisfactory on Pt, Ta, Mo, and W. Spodumene was selected as it gave the greatest ratios of Li^7/Li^6 in Hundley's work, as has been mentioned, and as this type of source [23] has been widely used in other experiments where a knowledge of the relative abundance of the lithium isotopes is of interest in some cases.

This type of source is activated simply by heating for a short time in vacuum to a high temperature (compared to the normal temperature for emission after the source is activated). The temperature of the filament is slowly raised until the ion current increases greatly and suddenly. Without this treatment it is difficult to secure steady emission and the efficiency of the source is low. After the activation, large ion currents can be secured at temperatures which were previously too low for appreciable emission. By accident, at one time, a pressure of 0.6 barye of air suddenly appeared in the apparatus but did not affect the steadiness of the source at the new emission value imposed by the scattering and absorption of the ions.

For the other alkalis similar minerals [24] were used, jadeite for Na, leucite for K as used by Read,[23] and pollucite for Cs which has been utilized by Thompson and Mitchell.[23] For rubidium ions an artificial silicate has been made by a method similar to that used by Lemberg [25] to introduce Na into leucite. A small quantity of powdered leucite was intimately

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[23] G. E. Read, *Phys. Rev.*, **31**, 629 (1928).
I. W. Cox, *Phys. Rev.*, **34**, 1426 (1929).
R. B. Sawyer, *Phys. Rev.*, **35**, 1090 (1930).
J. S. Thomson, *Phys. Rev.*, **35**, 1196 (1930).
A. C. G. Mitchell, JOUR. FRANK. INST., **210**, 269 (1930).

[24] The Spodumene from Keystone, S. Dakota, Jadeite from Burma, and Leucite from Albano, Rome, Italy were purchased from Ward's Natural Science Establishment, Rochester, New York. The Pollucite, excellent crystal clear fragments, were a gift from the General Electric Company, courtesy of Dr. E. E. Charlton and Mr. L. M. Willey.

[25] Lemberg, *Zs. G. Ges.*, **28**, 611 (1876).

mixed with rubidium chloride and the mixture was fused in an alundum crucible by an oxygen gas flame. A clear glass-like bead results which may then be powdered and applied to a filament in the usual way. As these sources in the author's opinion and experience are far superior to Kunsman sources in ease of manipulation, quantity of emission and ease of technique of activation, it was thought worthwhile to investigate the purity of emission as has been done for Kunsman sources by Barton, Harnwell, and Kunsman.[26] Irrespective of whether the alkalis exist in the silicate lattice as ions, or whether the process of ionization is governed by considerations similar to that introduced by Langmuir and Kingdon,[27] the relative amounts of the ions of different alkalis appearing in emission is a function of the temperature of the filament and these measurements are only roughly quantitative. In general, if two or more alkali metals are present in the source material in equal amounts, the element of lowest ionization potential will contribute most to the total ion current at a temperature so low as just to give appreciable ion emission. Similarly, for a given current density from the emitting source, pollucite may be run at a lower temperature than leucite, jadeite or spodumene. Pollucite coated filaments may be activated merely by admitting air to the filament after it has once been heated in vacuum to clean the surface next to the attached mineral. All these phenomena involve considerations consistent with the idea of thermal ionization as developed by Langmuir and Kingdon.

By suitably changing the magnetic field, ions of different e/m may be brought to a focus at the same voltage. Measurements of the purity of these sources were made by this method corresponding to conditions under which positive ion sources are ordinarily used.

In the measurements of the purity of the sources the percentages of impurities are referred to the most abundant isotope taken as 100 per cent. In the case of spodumene (lithium) at 340 volts, no cæsium was present, no rubidium, less than 0.01 per cent. potassium and 4 per cent. sodium represented the only impurities. Jadeite (sodium) contained only

[26] H. A. Barton, G. P. Harnwell, C. H. Kunsman, *Phys. Rev.*, **27**, 739 (1926).
[27] I. Langmuir and K. H. Kingdon, *Proc. Roy. Soc.*, **107**, 61 (1925).

0.03 per cent. of K^{39}. The only impurity in leucite (potassium) was sodium, which was less than 0.04 per cent. of the K^{39} peak at 700 volts. The only major impurity in the rubidium source was a potassium peak existing to 12 per cent. of the rubidium peak when tested at 1600 volts. The pollucite (cæsium) gave, as a result of three tests, less than 1 per cent. rubidium, 2 per cent. potassium, and a just-detectable amount of sodium. It is interesting to note that rubidium does not appear in the chemical analyses of this mineral. The tests on pollucite were made first, so that the presence of rubidium is not fortuitous and is correctly attributed to the mineral. The sources were not examined for H or H_2 which might have been present.

Positive Ions of Barium and Strontium.

It is of interest to record that Ba^+ and Sr^+ were detected from Mo, Pt, Ta and W filaments coated with $BaCo_3$ and $SrCo_3$. A similar series of experiments showed Ba^+ and Sr^+ ions when these filaments were coated with BaO and SrO as would be expected. No ions were detected from filaments coated with a powdered Ba–Al alloy or Sr–Al alloy.[28] No ions were found when a nickel filament containing 0.15 per cent. of Ba was heated to a temperature sufficient to reduce the cross-section by 50 per cent. in two hours.[29] No ions of barium, strontium, or calcium were detected from a coating of brewsterite on Ta and on Pt. Brewsterite is a silicate somewhat similar to pollucite. The sources provided by the carbonates and oxides were not intense enough nor stable enough to allow analysis of the isotopic constitution of Ba and Sr, which forced the abandonment of a series of experiments attempting to analyze these elements. Kunsman sources were tried but the necessary long period of reduction could not be successfully completed owing to the poisoning effect of gases evolved from the tube walls, so that the intensity of emission never attained a practical value. The identification of the positive ions from oxide coated filaments demonstrates that such

[28] These alloys were a gift from the General Electric Company, courtesy of Dr. E. E. Charlton.

[29] This material was very kindly supplied by Mr. D. W. Randolph of the A. C. Spark Plug Company. This alloy was designated as No. 377 containing 0.15 per cent. barium, 2 per cent. manganese and the balance nickel.

emission of Ba^+ and Sr^+ can occur as has been claimed by Glass and has been shown by Kozanowski and Williams within rather wide limits.[30]

III. THE ISOTOPES OF SODIUM AND POTASSIUM.

Sodium.

With high resolving power and intense ion sources it appeared possible to attain a sensitivity comparable with the recent results obtained by band spectra analysis,[31] for the detection of isotopes of a specific element existing in small abundance relative to the main isotope of the element. Be^8, C^{13}, N^{15}, O^{17} and O^{18} have been discovered by band spectra analysis in amounts ranging from 1/700 to 1/8600 of the most prevalent isotopes. Using the same apparatus as has been previously described in the work on lithium, sodium was analyzed using heated jadeite as a source of sodium ions. A typical analysis of sodium is shown in Fig. 4. Once the Na^{23} peak is located, the region around any other atomic weight may be examined carefully and thoroughly for minor peaks. Three such analyses were made. One part in 3000 of Na^{21} or Na^{25} could have been detected if present, but did not appear. The background and slope of the curves were too great at Na^{24} to permit of an estimate of the minimum detectable amount of Na^{24}. The background at Na^{22}, however, was in the neighborhood of 40 divisions and one part in 800 could have been detected if present. To obtain a better idea of the sensitiveness of this analysis the peak height corresponds to an electrometer deflection of approximately nine meters while the background due to strays was less than one centimeter at Na^{21}, and at Na^{25} was two and a half centimeters.

Analyses of sodium and potassium have been made before [32] but never with the sensitivity attained in the present

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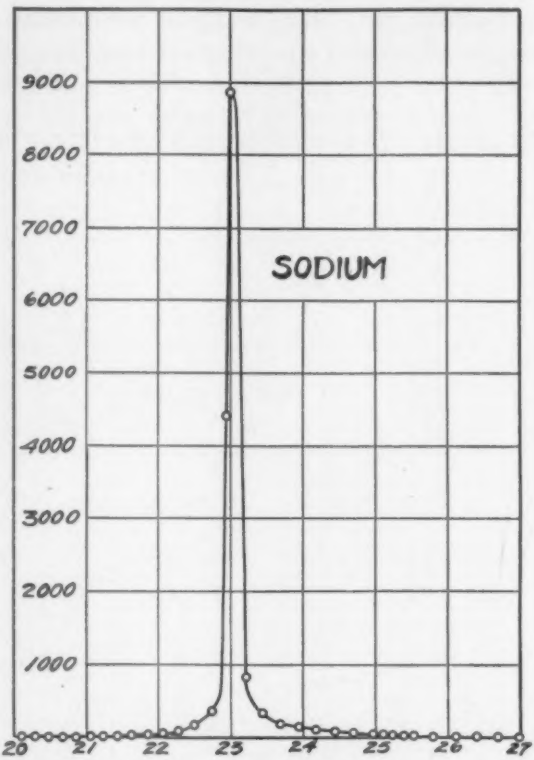
[30] M. S. Glass, *Phys. Rev.*, **28**, 521 (1926). H. N. Kozanowski and N. H. Williams, *Phys. Rev.*, **36**, 1326, 1930.

[31] Be^8, W. W. Watson, *Phys. Rev.*, **36**, 1019, 1930. C^{13}, A. S. King and R. T. Birge, *Nature*, **124**, 182, 1929; *Phys. Rev.*, **34**, 376, 1929; R. T. Birge, *Phys. Rev.*, 34, 379, 1929. N^{15}, S. M. Naudé, *Phys. Rev.*, **34**, 1498, 1929; *Phys. Rev.*, **35**, 130, 1930; *Phys. Rev.*, **36**, 334, 1930. O^{17}, O^{18}, W. F. Giauque and H. L. Johnston, *Nature*, **123**, 318, 831, 1929; *J. Am. Chem. Soc.*, **51**, 1436, 3528, 1929.

[32] A. J. Dempster, *Phys. Rev.*, **11**, 316, 1918. G. P. Thomson, *Phil. Mag.*, 42, 857, 1921. F. W. Aston, *Nature*, **107**, 72, 1921; *Nature*, **111**, 739, 1923; *Phil. Mag.*, **42**, 436, 1921.

work, which is of the same order as that obtained in the analysis of band spectra.

FIG. 4.



Analysis of sodium. Abscissas, atomic weight units; ordinates, ion current in arbitrary units.

Potassium.

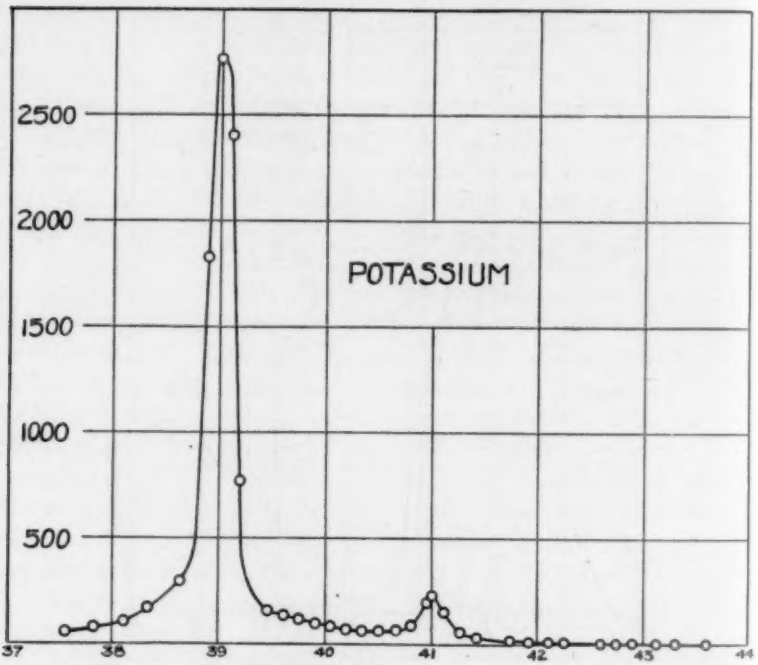
From examination of regularities occurring in the nuclear constitution of the elements and their isotopes, Beck [33] predicted the occurrence of K^{43} and Fournier [34] has predicted that K^{40} should exist. Harkins [35] has suggested K^{40} or K^{41} as the isotope responsible for the radioactivity of potassium, Kossel[36]

[33] G. Beck, *Zeit. f. Physik*, **47**, 407, 1928.
[34] G. Fournier, *J. de Physique et le Radium*, **1**, 194, 1930.
[35] W. D. Harkins, *Natl. Acad. Sci. Proc.*, **11**, 630, 1925.
[36] W. Kossel, *Phys. Zeit.*, **20**, 265, 1919.

has suggested K^{43}. More recent work [37] has shown that K^{41} is the radioactive isotope of potassium.

Potassium was analyzed in the mass-spectrograph using heated leucite as an ion source. Figure 5 illustrates a typical analysis for potassium. Three analyses were made and from these it may be concluded that there is less than one part in

FIG. 5.



Analysis of potassium. Abscissas, atomic weight units; ordinates, ion current in arbitrary units.

1500 of K^{43}, less than one part in 600 of K^{42}, and less than one part in 300 of K^{40} in reference to K^{39} if these other isotopes exist at all. The background due to strays at K^{43} was zero, one part in 1500 would represent a deflection of 1.8 mm. on the electrometer scale.

In conclusion the writer wishes to thank Professor W. F. G. Swann for his interest in this work and the privilege of working

[37] G. Hevesy, *Nature*, **120**, 838, 1927. G. Hevesy and M. Lögstrup, *Z. anorg. allgem. Chem.*, **171**, 1, 1928. M. Biltz and H. Ziegert, *Phys. Zeit.*, **29**, 197, 1928.

at the Bartol Research Foundation of The Franklin Institute. The author also wishes to thank the National Research Council for the opportunity to do this research. It is a pleasure also to acknowledge the careful work of Mr. O. Steiner, who constructed the large magnet and auxiliary apparatus and contributed many refinements to the mechanical design.

Further study of isotopes is being made using photographic recording of the ions using an apparatus of wider scope which permits the use of ions from sources of any nature, homogeneous in energy or not.

Constitution of Rhenium. F. W. ASTON. (*Nature*, April 18, 1931.) Aston admitted to the discharge tube the vapor of Re_2O_7, a crystalline solid that volatilizes slightly, and, when no mass spectrum was obtained, the solid was heated in the tube by a beam of cathode rays. The second method likewise failed to give results. The experimenter then took up the problem of getting the mass spectrum of gold. There was some reason to expect results for gold by using the tube without cleansing it of rhenium. "Although no lines of gold were visible, the doublet lines of rhenium appeared in great intensity and in addition were repeated 16, 32 and 48 units higher as ReO, ReO_2, and ReO_3, so giving unusually convincing evidence of its constitution."

Rhenium has two isotopes 185 and 187 respectively, in the ratio of abundance 1.62 : 1. "From these provisional values the atomic weight on the chemical scale works out at 186.22 ± 0.07, in good agreement with Hönigschmid's latest value of 186.31. The strongest isotope of rhenium is isobaric with the weakest of osmium."

G. F. S.

NOTE ON THE DIFFUSE BANDS OCCURRING IN MIXTURES OF AMMONIA AND EXCITED MERCURY VAPOR.

BY

ALLAN C. G. MITCHELL,

Bartol Research Fellow.

BARTOL RESEARCH FOUNDATION
Communication No. 58.

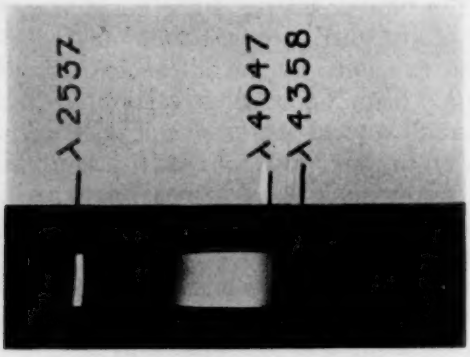
A few years ago, Dickinson and Mitchell [1] reported the occurrence of diffuse bands when a mixture of mercury vapor and ammonia were irradiated by light from a water cooled quartz mercury arc lamp. According to their work, two diffuse bands were observed; one in the blue-green with visual maximum about λ 5100 Å., and one in the ultra-violet extending from λ 3170 Å. to λ 3650 Å. with a maximum around λ 3370 Å. On account of technical difficulties they were not able to photograph the blue-green band nor could they measure the total extent of the ultra-violet band. Gaviola and Wood [2] confirmed the existence of the ultra-violet band and found that it extended from λ 2900 Å. to λ 4000 Å.

Using a small quartz spectrograph with rather wide slit, the author has obtained photographs of the ammonia fluorescence, when ammonia gas at 3 mm. pressure and mercury vapor at room temperature were radiated by light from a water cooled (and magnetically deflected) quartz mercury arc. The fluorescence appears to be one continuous band extending from about λ 2700 Å. to beyond the λ 5461 Å. line of mercury. A minimum of intensity, appearing at about λ 5200 Å. is probably due to the insensitiveness of the (Speedway) plate in this region. A densitometer record of the plate was obtained and an analysis of the curve shows that the band extends, on the short wave-length side, to about λ 2600 Å., although this limit is somewhat uncertain due to the weak intensity in this region, and to the large slit widths used. On the long wave-length side the band could be traced to

[1] R. G. Dickinson and A. C. G. Mitchell, *Proc. Nat. Acad. Sci.*, **12**, 692 (1926).
[2] E. Gaviola and R. W. Wood, *Phil. Mag.* **6**, 1191 (1928).

about λ 5600 Å. The maximum appeared at λ 3400 Å. It seems certain, therefore, that the ammonia fluorescence consists of one very diffuse band extending from λ 2700 Å. to λ 5600 Å. with a maximum at λ 3400 Å. The fact that a smaller extension of the band was reported previously, is due to the fact that the intensity falls off rather rapidly from the maximum so that long exposures are necessary to catch the outlying portions of the band.

At one time, Dickinson and the writer [1, 3] pointed out a similarity between the diffuse bands observed at that time in ammonia and the diffuse bands appearing when boiling mercury vapor is excited to fluorescence by radiation. That the similarity was probably fortuitous was pointed out by the writer [3] from the fact that the intensity of the maximum of the band depends markedly on the ammonia pressure.[4] A comparison between the photograph reproduced here and one given by Houtermans [5] of the bands in boiling mercury, shows that the bands are not identical.



[3] A. C. G. Mitchell, *Journ. Amer. Chem. Soc.*, 49, 2699 (1927).

[4] Gaviola and Wood (l.c.) attribute to the writer the statement that the diffuse bands observed in boiling mercury are due to ammonia as an impurity. The writer feels that the authors in question must have misquoted him in this matter, as no such statement has ever been made by him in any of his papers, nor has it ever represented his belief regarding the situation.

[5] F. G. Houtermans, *ZS. f. Phys.*, 41, 140 (1927).

THE SOLUBILITIES OF ALKALI BROMIDES AND FLUORIDES IN ANHYDROUS METHANOL, ETHANOL, AND BUTANOL.

BY

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INTRODUCTION.

The solubilities of the numerous inorganic salts in anhydrous compounds of alcoholic structure have been accorded but comparatively little attention until recently. Much of the work which has been recorded presents data concerning only aqueous methyl and ethyl alcohols,[1] while the results attained exhibit a wide divergence with different investigators.

As Kirn and Dunlap [2] have suggested, the discrepancies obtaining in these researches may be attributed, at least in part, to the introduction of error in the ultimate results engendered by the presence of varying proportions of water in the alcohols, or the probability that moisture may have adversely influenced the experimental data by producing contamination of the test solutions during the period of examination. The present contribution considers the relation existing between the degrees of solubility of the sodium and potassium derivatives of hydrobromic and hydrofluoric acids —at varying temperatures—and the increasing molecular weights of specific organic solvents in whose structure the hydroxyl group is present.

MATERIALS.

The salts employed in this research were of c.p. quality; further purification was accomplished by repeated recrystallization from pure distilled (pH 6.8) water. Following this treatment, the compounds were washed and then pulverized,

[1] Landolt-Börnstein: Physikalish-Chemische Tabellen, pp. 730–7; C. A. Lobry de Bruyn: *Z. physik. Chem.*, **10**, 783 (1892).

[2] Kirn and Dunlap: *J. American Chem. Soc.*, **53**, 391–4 (1931).

and finally heated in an electric oven at a moderate temperature until no further decrease in weight was experienced. These were then transferred to special ground-glass stoppered bottles, and so maintained until required. Chemical analysis of the purified products showed them to contain but faint traces of Fe, Cl, and SO_3, the portions of these elements being so minute as to be negligible.

The ethanol used in the work was prepared from the so-called "absolute" grade; complete dehydration was accomplished by the combined actions of calcium oxide and activated aluminium,[3] while the elimination of the lower aldehydes present in the solvent was attained by the application of the method of Paul.[4] A product possessing a density value equivalent to 100 per cent. C_2H_5OH was obtained in this manner.

Methanol and butanol of the requisite character were produced by careful fractionation of special grades of these substances; following this process, the alcohols were subjected to continuous refluxing and subsequently re-fractionated. Great care was exercised to prevent the formation of aluminium alcoholates [5] at this time, and the proper pressure and stem corrections were made during the determinations of the boiling-points. Solubility tests with highly-purified potassium chloride [6] were subsequently carried out in the effort to ascertain whether complete dehydration of the alcohols (methanol and butanol) had occurred. The liquids were protected at all times from moist air during the distillations, by means of barium perchlorate tubes.

APPARATUS.

The technic applied in the production and for the obtainment of experimental samples of solutions of the haloid salts was that developed by Weber and Dunlap [7] and later modified

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[3] Bulletin of the National Bureau of Standards No. 197.

[4] Paul: Diss. Würzburg; *Z. anal. Chem.*, **35**, 647–59; J. Chem. Soc. London Abstr. **72**, 235–6.

[5] Berger: *Compt. rend.*, **157**, 717–8 (1906).

[6] Kirn and Dunlap: *J. American Chem. Soc.*, **53**, p. 392 (1931).

[7] Goodhue and Dunlap: *ibid.*, **50**, 1916–1922 (1928). Also, Weber and Dunlap: *Ind. Eng. Chem.*, **19**, 481 (1927).

by other workers.[2] This consisted, primarily, of providing a 500–ml. Kjeldahl flask with a cork stopper, this having been previously extracted with ethyl alcohol. To prevent moisture from coming in contact with this cork, a strip of thin rubber, provided with two small openings for the condenser and the sampling tube, was fastened over the top portion of the container. The lower end of the sampling tube was fitted with a shortened Soxhlet thimble for the purpose of filtering out the suspended salts. A desired amount of the sample could be obtained by forcing air previously dried into the flask, the driers at the top of the condenser performing this function. Adequate precautions were taken to obviate the possibility of removing some of the dissolved salt by adsorption. The temperature of the thermostat used in the experimental portion of the work considered here was controlled to one-tenth of one degree.

METHOD.

The test solutions were prepared in the following manner: An excess of the purified salt was placed in the flask, and the solvent added. The condenser with the filtering device was attached and placed in the thermostat, submerging the flask. Experimentation established the time required for saturation. Although a period of two hours was sufficient to effect this, the contents were allowed to remain undisturbed for three hours. After this interim had elapsed, two samples of 25 ml. were removed, and then placed in air-tight brown glass bottles which were kept in a desiccator until their temperature was in equilibrium with that of the laboratory.

The experimental solutions of the alkali bromides in ethyl and methyl alcohols were diluted with distilled water to a volume of fifty milliliters in 200 ml. Erlenmeyer flasks, and then titrated with silver nitrate solution in the presence of potassium tetrabromofluorescein as adsorption indicator. About one per cent. before the equivalence-point the silver halide flocs out, and when the titration is continued with vigorous stirring the precipitate suddenly becomes intensely red-colored; this stage usually also coincides with the "clear-point." The accuracy and sensitivity of this method for the determination of very dilute bromide solutions cannot be

questioned.[8] The butanol solutions of the bromides as well as those of the fluorides were, due to their immiscibility with water, first carefully evaporated to dryness, and then dissolved in water before being subjected to ultimate examination. Finally, it may not be amiss to remark that titration was made quite rapidly in diffused light; direct sunlight was avoided, because, as is well known, sensitization of the silver halide is greatly increased in the presence of the dye employed as indicator.

The various methods for the determination of fluorides were carefully considered with the view to the selection of one that might be suitable for use in estimating the amounts of dissolved alkali fluorides in the solutions under examination. None of these appeared to possess in entirety the qualifications considered necessary to the attainment of results in keeping with the nature of this work. The plan to determine these constituents by chemical procedure was, therefore, abandoned, and it was decided to apply the following method:

The solutions containing the fluorides were transferred to casseroles which had been most carefully weighed; then evaporated to dryness in the electric oven, and reweighed. Each of the determinations made was checked, and it was found that the average deviation was extremely slight in the methanol and ethanol solutions, while that obtaining in the butanol solutions was but slightly higher but still so small as to be rendered negligible. Table I furnishes the data obtained by the examination of the methanol solutions of the alkali halogens. The results are expressed in moles of solute per mole of solvent.

TABLE I.

Moles of Salt per Mole of Methanol.

Temperature °C.	NaBr	KBr	NaF	KF
20	0.00694	0.00702	0.00316	0.00106
30	.00663	.00689	.00337	.00093
40	.00661	.00673	.00351	.00083
45	.00648	.00651	.00363	.00072
50	.00605	.00638	.00365	.00069
55	.00548	.00617	.00371	.00051

[8] Fajans and Wolf: *Z. anorg. allgem. Chem.*, **137**, 221 (1924).

It will be observed that each of the alkali bromides and potassium fluoride show a tendency to dissolve less freely with an increase in the temperatures of the solutions; sodium fluoride, however, is characterized by a slight increase in solubility with the corresponding rise in temperature. Table II records the results encountered in determining the proportions of the compounds dissolved in anhydrous ethanol.

TABLE II.

Moles of Salt per Mole of Ethanol.

Temperature °C.	NaBr	KBr	NaF	KF
20	0.00198	0.00176	0.00104	0.00084
30	.00207	.00195	.00119	.00076
40	.00203	.00219	.00131	.00054
45	.00186	.00230	.00159	.00039
50	.00158	.00221	.00173	.00018
55	.00129	.00209	.00197	.00008

The solubility of sodium bromide in ethanol increases until the peak is reached, and then decreases, while that of potassium fluoride diminishes regularly as the temperature rises. A steady increase in the quantities of potassium bromide and sodium fluoride dissolved in the anhydrous alcohol continues with the absorption of heat by the solvent.

Table III enumerates the results of continued experimentation—the solvent effect of *n*-butyl alcohol is considered in this series.

TABLE III.

Moles of Salt per Mole of n-Butanol.

Temperature °C.	NaBr	KBr	NaF	KF
20	0.000089	0.000070	0.000053	Insoluble.
30	.000096	.000081	.000072	Insoluble.
40	.000096	.000085	.000076	Insoluble.
45	.000097	.000088	.000083	Insoluble.
50	.000084	.000092	.000087	Insoluble.
55	.000089	.000092	.000095	Insoluble.

In these solutions an increase in solubility, though very slight, is experienced with the exception of sodium bromide, which reaches a maximum solubility at 45° C., and then

decreases somewhat. Potassium fluoride, as will be noted, is insoluble in the normal-chain compound.

DISCUSSION.

While the *modus operandi* involved was considerably expedited and uniformity and accuracy of results insured, it was believed, by the application of the several analytical methods employed, the author wishes to stress the fact that numerous additional, and—where such proceeding was feasible—confirmatory tests were meticulously performed in the effort to discover and, in this event, to correct or compensate for any differences that might accrue as a failure to previously discern the possible effect of errors that may have been introduced or even induced, *e.g.*, by variations in the periods of time allotted to the determination of the compounds in each test sample; rapidity and mode of titration, and related conditions capable of being influenced by the technic of the worker.

Careful observation at this time verified most convincingly the conclusion that results attained by the application of the procedures described were most gratifying as regarded absence of experimental error of any tangible degree—and consequently insured consistent accuracy in the final data recorded and presented in this research.

SUMMARY.

(1) The solubilities of certain of the alkali bromides and fluorides in specific anhydrous compounds of alcoholic structure have been studied.

(2) Sodium bromide, potassium bromide and potassium fluoride dissolve less freely in methanol as the temperature of the solvent is increased. The solubility of sodium fluoride is slightly increased under similar conditions.

(3) The proportion of sodium bromide dissolving in ethanol becomes greater until the peak is reached; solubility then diminishes. Continued increase in temperature retards the dissolution of potassium fluoride in ethyl alcohol, while a steady increase in the quantities of potassium bromide and sodium fluoride dissolving in this medium is observed.

(4) As the temperature of the *n*-butanol solutions is elevated, a slight acceleration in the solubilities of potassium

bromide and sodium fluoride obtains, while that of sodium bromide attains a maximum point at 45° C., and then decreases. The potassium salt of hydrofluoric acid is insoluble at each degree of temperature noted.

(5) The solubility of each of the compounds considered decreases as the molecular weight of the alcohol employed as solvent increases.

Use of Hydrocyanic Acid Gas for Fumigating.—In a report recently published by the United States Public Health Service, the use of various fumigating materials, particularly hydrocyanic acid gas, is discussed. Hydrocyanic acid gas is a deadly gas. Persons unfamiliar with its use and effect should not expose themselves to it. This report indicates that trained fumigators can handle the most deadly gases with safety, both to themselves and others. It is, on the other hand, quite as true that in the hands of the uninformed or careless, many forms of fumigation are a menace to all concerned.

The report emphasizes that fumigating materials, particularly the deadly gases, should be handled only by persons trained in their use and who have the necessary equipment, such as gas masks, to protect themselves as the occasion requires. These gases should never be used without the full knowledge and consent of the local public health or police authorities. Hydrocyanic acid gas should never be used in buildings without combination with a warning gas.

R.

Influence of Light on the Oxidation and Rancidity of Fats. According to COLIN HENRY LEA (*Proc. Roy. Soc.*, B, 1931, CVIII, 175–189) light accelerates the oxidation of fats, and the reaction is autocatalytic. Exposure to direct sunlight produces rancidity, even though the period of exposure be only a few minutes. The content of active oxygen (organic peroxides) and the response to the Kreis reaction for rancidity (formation of a pink color with phloroglucinol and hydrochloric acid in ether-benzene solution) tend to increase simultaneously. Low temperatures favor the formation of peroxides, bright sunlight the development of rancidity. The acidity of the fat is not influenced, at least during the earlier stages of these changes.

J. S. H.

Spectrographic Study of Animal Tissues. H. MUNRO FOX and HUGH RAMAGE (*Proc. Roy. Soc.*, B, 1931, CVIII, 157–173) have made spectroscopic examinations of 146 specimens including either the whole animal or the dissected organs of approximately 50 species of invertebrates and 3 men. Iron and copper were always present. Manganese, strontium, and lithium were widely distributed but not invariably present. Silver and lead were widely but irregularly distributed. Nickel was found more frequently than cobalt, which occurred only in marine animals. Rubidium was present in some species. As to cadmium and fluorine, each was found in only one species. Barium and cæsium did not occur in any of the specimens.

J. S. H.

THE DEVELOPMENT OF THE SOLARIZED LATENT IMAGE.*

BY

A. P. H. TRIVELLI and E. C. JENSEN.

Introduction.—In a series of investigations on solarization in these Laboratories,[1] one of us [2] came to the conclusion that from the two proposed theories of the solarized latent image, the progression and the regression theory, the latter seems to be in better agreement with the experimental results than the first. This conclusion leads to the construction of a tentative picture of the formation of the solarized latent image based upon the speck growth theory of the latent image as it has been proposed by S. E. Sheppard, A. P. H. Trivelli, and R. P. Loveland.[3] According to this hypothesis the action, during exposure, of preëxisting specks on the surface of the silver halide grains of photographic emulsions is confined to increasing their size by accretion of photochemically reduced silver atoms to form a nucleus large enough to introduce developability. The photochemically liberated halogen is absorbed in part by the gelatin, and in part diffuses away. The remainder reacts by increasing pressure on the silver of the speck during the exposure, reducing more and more its speed of growth till a certain size is reached, after which the speck diminishes its size. The halogen photochemically liberated from the surrounding silver halide forms nondevelopable small silver specks equilibrating the distribution of the halogen pressure. After this stage is reached, the speck starts to grow again slowly at the same speed that the photochemically liberated halogen is absorbed, and diffuses. If, during the period when the size of the speck is diminished,

* Communication No. 465 from the Kodak Research Laboratories.

[1] Trivelli, A. P. H., and Loveland, R. P.: *J. Franklin Inst.*, 208: 731, 1929.

[2] Trivelli, A. P. H., and Jensen, E. C.: ibid., 209: 37, 1930. Trivelli, A. P. H.: ibid., 209: 373, 1930.

[3] Sheppard, S. E., Trivelli, A. P. H., and Loveland, R. P.: *J. Franklin Inst.*, 200: 51, 1925.

this size becomes smaller than the threshold value of the developable size of the speck, solarization is introduced by development. Hitherto two objections were raised against the regression theory of the solarized latent image. First, the fact that in the solarization region of exposure a progression of the amount of photochemically liberated silver has been observed, and second, that the theory could not be brought in agreement with the reactions in an amicroscopical homogeneous system. These objections are countered by the introduction of the concentration speck theory of the latent image. Lüppo-Cramer [4] gave experimental support to this solarization theory in later investigations of the distribution of silver iodide in the silver bromide grain.

Our investigations [2] on the correlations between different photographic characteristics have shown that there are in general very weak, or no, correlations between the regions of normal and solarized exposures. For instance, we were not able to detect a correlation between the contrast in the normal region of exposure and the contrast in the solarized region of exposure. According to the concentration speck theory of the latent image, this means that there must be another distribution of developable centers in the solarized region of exposure than in the normal region of exposure. It is, therefore, of interest to investigate the development of the solarized latent image in comparison with the development of the normal latent image.

Photographic Material and Development.—For these investigations use was made of a photographic gelatin emulsion containing pure silver bromide grains obtained by precipitation with potassium bromide of which the iodide content was less than 0.002 per cent. The free potassium bromide content of the coated plates was found by A. Ballard of these Laboratories to be about 0.03 per cent. of the total amount of silver bromide. The emulsion has a wide range of grain sizes as is shown by the size-frequency curve published by one of us in a previous investigation on the Herschel effect.[5] Development was effected with brush [6] in a bath at 17 degrees C.

[4] *Z. wiss. Phot.*, 27: 9, 1929.
[5] *J. Franklin Inst.*, 207: 765, 1929.
[6] Cf. W. Clark, *Phot. J.*, 65: 76, 1925.

± 0.1 degree, controlled by a thermostat with the following developers:

TABLE I.

Developing Agent.	Weight of Developer.	Sodium Sulfite.	Sodium Carbonate.	Water to
p-aminophenol.....	7.275 gms.	50 gms.	50 gms.	1000 c.c.
Pyrogallol.....	3.15 gms.	50 gms.	50 gms.	1000 c.c.
Hydroquinone.....	5.5 gms.	50 gms.	50 gms.	1000 c.c.

The sulfur dioxide content of the sodium sulfite was determined analytically and the actual amount calculated for an equivalent of 100 per cent. pure salt was used.

The hydroquinone developer was further used with the addition of $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, 16 and 32 gm. of potassium bromide per liter developer. Altogether 11 different developers were used representing a scale with different reduction potentials.

At every interval of development 5 strips were made and the average of the densities, measured with a Martens densitometer, was plotted. The strips were developed for 2, 3, 4, 5, 6, 7, 8, 10, 12, 16, 22 and 32 minutes. Development was stopped at the required time with diluted acetic acid (1 per cent); the plates were fixed in an acid fixing bath.

The Sensitometer.—The exposures were made with a non-intermittent sensitometer of 26 steps of $\sqrt{2}$ ratio. The light intensity was kept constant and the time of exposure was varied. The maximum time of exposure was 5791 seconds. The light source was a 500 candle power standard monoplane tungsten filament lamp, operated at 105 volts to give a color temperature of 3003 degrees K.

On account of the many and the long exposures it was necessary to keep the light intensity as constant as possible. For this purpose a voltage regulator was designed by A. L. Schoen of these Laboratories. A record of the voltage changes is shown in the above mentioned publications on the Herschel effect. In these investigations the deviations correspond to less than 6 per cent. intensity differences in the actinic part of the spectrum. No filters were used. The photographic plates were exposed to the range of the characteristic curve in two separate segments. The last step of the first segment,

including from the toe to the maximum density, received 755.86 m.c. exposure; the second segment commenced with a first step of 1059.07 m.c., making a close continuation of sequence of exposures. There was a diaphragm with opal glass at a distance of 99 cm. from the photographic plate. For the first segment the aperture produced an optical intensity of 0.117 m.c. on the plate; for the solarization segment the intensity was 950 m.c. This great difference of light intensity produced a failure of the reciprocity law. This reciprocity failure was investigated for this photographic emulsion by V. C. Hall and one of us[7] and found to have abnormal gamma curves with varying light intensity. Therefore, a continuous curve for the entire range of exposures could not be drawn because of the marked difference in density of the two adjacent ends of the curves.

Treatment of the Data.—Errors in exposures and in density readings are negligible compared with errors in development. The sensitometric determinations are in general sufficiently reliable to determine the shape of the curve, but smoother results are obtainable. The gamma of the curve for time of development was corrected by a method of smoothing suggested by L. A. Jones. Values from the H. & D. curves were plotted as functions of development time; the smoothed values from the density-time curves were then replotted as H. & D. curves. This may be repeated. The results obtained show that up to about 10 minutes development, the smooth curves are very reliable and represent the real data as closely as possible under these circumstances. Beyond 10 minutes development differences in thickness of the coating emulsion so influence the densities that the deviations in densities increase and the average values become less accurate.

Expression of Results.—Many data were collected in this way. It is out of the question, however, to publish complete tables, especially with the hydroquinone developers containing potassium bromide. It may be suggested that adequate comparison can be effected by:

(1) The graphic exposition of families of H. & D. curves for normal and solarized exposures for 2 to 32 minutes development in *p*-aminophenol, pyrogallol, hydroquinone, and hydro-

[7] *J. Franklin Inst.*, 208: 483, 1929.

quinone with 0.002N, 0.016N, and 0.269N potassium bromide solution in the developer.

(2) Comparative tables showing for different times of development the following: H. & D. speed, fog, gamma and maximum density for normal exposures, H. & D. speed of solarization, gamma ($-\gamma$) and minimum density for solarized exposures. These data are given for development with *p*-aminophenol, pyrogallol, hydroquinone and hydroquinone with potassium bromide from 0.002N to 0.269N solution in the developer.

(3) Tables of values of the correlation coefficient k and its probable error Q determined from Bravais-Pearson correlation formula and correlating:

(*a*) Density with the logarithm of the concentration of potassium bromide in the hydroquinone developer, determined for 4, 6, 8, 10, 12, 16, 22 and 32 minutes development, and for 13 different exposure steps in the power of $\sqrt{2}$ ratio in both normal and solarized regions of exposure.

(*b*) Density with gamma, determined for development in hydroquinone with the stated concentrations of potassium bromide in both normal and solarized regions of exposures. These data are sufficient for the deduction of the functions and constants.

To determine the H. & D. speed of the solarized part of the characteristic curve, a straight line is drawn through the maximum density parallel to the exposure axis. This line represents log E units of the same value as the exposure axis. A tangential line through the inflection point of the first reversal of the solarization represents the contrast of the first reversal of the solarization expressible as the negative value of gamma. Where this line will intersect the tangential line through the maximum density parallel to the exposure axis the inertia of solarization is given. The reversed value of this inertia multiplied for convenience by 10^7 gives the H. & D. speed of the first reversal of the solarization (cf. 2).

To determine statistically whether there is, or is not, a correlation between two groups of observations, a and b, the obtained data a may be arranged in increasing or in decreasing values, and it may be seen in how far the obtained data b in the other group increase or decrease at the same time.

The simplest correlation is direct proportionality between two sets of data, represented graphically by a straight line relation. If the data are not very accurate, however, it is sometimes hard to determine whether or not we are dealing with a direct proportionality. A. H. Nietz[8] assumes that the relation between the density and the logarithms of the corresponding bromide concentrations in a developer is expressed by a direct proportionality. The position of this line he then determines by the method of least squares, from a set of data, which represent sometimes the average of 50 and even 60 determinations. In some cases Nietz ran short of the particular batch of emulsion under investigation or of developer needed. Although our observations are not so numerous, it will be shown that the correlation between the density and the logarithms of the corresponding bromide concentrations in the developer can be investigated with a much smaller number of data by employing the Bravais-Pearson correlation formula for the determination of the correlation coefficient and its probable error. If this coefficient is 1 or very near 1 we are sure, or practically sure, that we are dealing with a direct proportionality. This investigation then can be extended to the data observed in the solarization region.

The correlation coefficient can be determined in the following way. Let us take two sets of data, a and b, and add the values of each set of data separately:

$$a_1 + a_2 + a_3 + \cdots + a_n = \Sigma a,$$
$$b_1 + b_2 + b_3 + \cdots + b_n = \Sigma b,$$

then the arithmetical mean is:

$$\bar{a} = \frac{\Sigma a}{n} \text{ and } \bar{b} = \frac{\Sigma b}{n},$$

where n is the total number of observations in a set of data.

Now we determine the differences between the observed data and the arithmetical mean:

$$\xi = a - \bar{a},$$
$$\eta = b - \bar{b}.$$

[8] Nietz, A. H.: *Theory of Development*, Monograph No. 2 from the Kodak Research Laboratories, Eastman Kodak Company, Rochester, N. Y., 1922, p. 49.

These values may be positive or negative. The correlation coefficient k is then given by the Bravais-Pearson product-moment coefficient:

$$k = \frac{\Sigma\xi\eta}{\sqrt{(\Sigma\xi)^2(\Sigma\eta)^2}}.$$

If $k > 0$, then b on the whole increases with a. If $k < 0$ then b on the whole decreases with increasing a. If $k = 0$ there is no correlation; if $k = 1$, the extreme value is given, meaning direct proportionality. The probable error Q of the correlation coefficient is given by:

$$Q = 0.675\frac{1 - k^2}{\sqrt{n}},$$

where n is the number of pairs of obtained data.

The number of times the correlation coefficient is greater than its probable error is expressed by k/Q. If k/Q is 3 or more, we may say that there is a correlation; if k/Q is 2 or 2.5 more observations are required, whether or not there is a correlation; if k/Q is < 2, we may say that no definite correlation can be found.

Discussion of the Results.—In Fig. 1 are given the H. & D. curves obtained with the hydroquinone, the pyrogallol and the *p*-aminophenol developer, all without the addition of any potassium bromide as fog remover. In Tables II, III and IV are given the numerical values of fog, H. & D. speed,

TABLE II.

Hydroquinone.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.24	32.5	.56	1.33	565	.65	.78
6′	.42	40.0	.86	2.12	552	.75	1.18
8′	.60	32.5	1.14	2.70	578	.86	1.48
12′	.96	24.6	1.70	3.52	552	.91	1.96
16′	1.32	31.0	1.90	4.03	420	.94	2.30
32′	2.68	—	1.24	4.88	420	.78	3.30

FIG. 1.

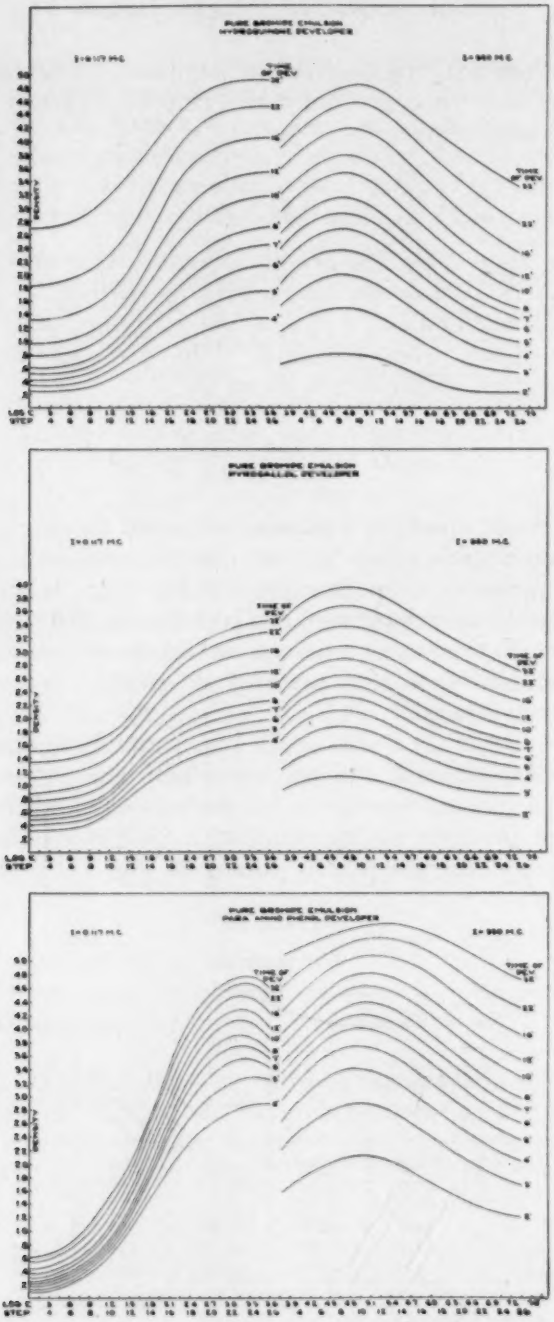

PURE BROMIDE EMULSION
HYDROQUINONE DEVELOPER
PURE BROMIDE EMULSION
PHENIDONE DEVELOPER
PURE BROMIDE EMULSION
PARA AMINO PHENOL DEVELOPER

TABLE III.

Pyrogallol.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.32	31.0	.80	1.66	578	.51	1.10
6′	.48	31.0	.98	1.98	526	.54	1.42
8′	.62	35.6	1.08	2.26	578	.53	1.64
12′	.87	44.8	1.24	2.70	503	.55	2.00
16′	1.10	65.4	1.24	3.01	439	.59	2.26
32′	1.50	85.5	1.35	3.45	481	.62	2.70

TABLE IV.

P-aminophenol.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.9	12.1	1.58	2.89	348	.74	2.04
6′	.17	8.8	2.21	3.55	277	.76	2.60
8′	.23	9.4	2.36	3.91	241	.80	2.98
12′	.35	12.1	2.40	4.30	191	.77	3.53
16′	.44	14.2	2.42	4.49	145	.75	3.91
32′	.60	14.2	2.64	4.77	88	.58	4.72

gamma and $D_{max.}$ for the normal region of exposures and of H. & D. speed $\times 10^6$, negative gamma and $D_{min.}$ for the solarization region of exposures. We find that the *p*-aminophenol developer gives a lower H. & D. speed than the hydroquinone or the pyrogallol developer. This is due to the fact that the *p*-aminophenol developer gives low fog values. If we remove the fog obtained with the hydroquinone or pyrogallol developers we get H. & D. speed values of the same order as the *p*-aminophenol developer. If we also take into account the contrast (gamma), we see that the *p*-aminophenol developer gives a much higher gamma than the hydroquinone and the pyrogallol developer. Hydroquinone and *p*-aminophenol give about the same solarization contrast. Pyrogallol gives the lowest solarization contrast. The maxi-

mum density is, however, the lowest with pyrogallol. Hydroquinone gives a greater rate of increase of maximum density with time of development and also a lower minimum density in the solarization region than pyrogallol or *p*-aminophenol.

In Fig. 2 are given the results of the development with hydroquinone in 0.002*N*, 0.016*N* and 0.269*N* potassium bromide solution. In Tables V, VI and VII are given the corresponding numerical values of fog, H. & D. speed, gamma and maximum density for the normal region of exposures and of H. & D. speed $\times 10^6$, negative gamma and minimum density for the solarization region of exposures. We found that the solarization contrast shows increasing negative gamma values the more potassium bromide is added to the hydroquinone developer, which seems to approach a limit at

TABLE V.

Hydroquinone with KBr 0.002N.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.18	17.1	.62	1.39	400	.65	.76
6′	.34	19.6	1.10	2.08	333	.84	1.24
8′	.54	16.3	1.51	2.64	348	.85	1.62
12′	.88	12.9	2.26	3.48	290	.92	2.27
16′	1.16	17.9	2.26	3.95	200	1.01	2.78
32′	2.14	77.5	2.04	4.58	80	.37	4.04

TABLE VI.

Hydroquinone with KBr 0.016N.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.04	.71	.25	.32	175	.90	.20
6′	.04	.85	.81	.98	149	1.33	.46
8′	.04	1.5	1.08	1.56	152	1.50	.74
12′	.04	3.1	1.48	2.50	145	1.68	1.33
16′	.06	4.3	1.84	3.16	115	1.77	1.88
32′	.56	8.6	2.60	4.38	85	1.36	3.00

FIG. 2.

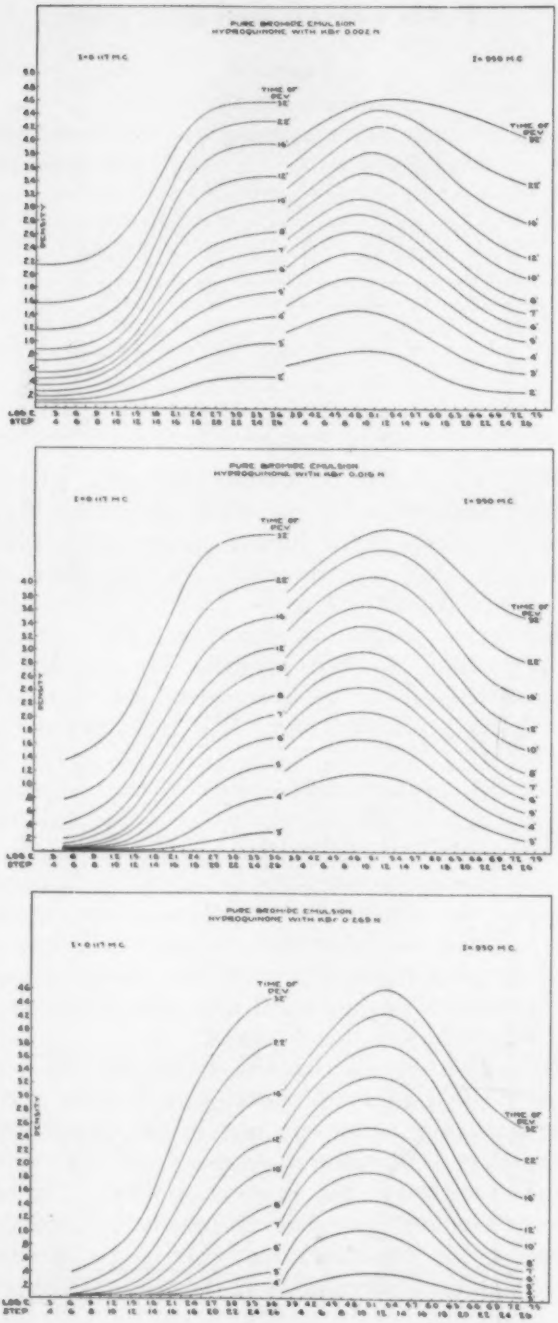

PURE BROMIDE EMULSION
HYDROQUINONE WITH KBr 0.002 N
I=0.117 M.C.
I=950 M.C.
TIME OF DEV.
DENSITY
LOG E STEP

TABLE VII.

Hydroquinone with KBr 0.269N.

Normal Exposures					Solarization Exposures		
Time of Dev.	Fog.	H. & D. Speed.	γ.	$D_{max.}$	H. & D. Speed $\times 10^6$.	$-\gamma$.	$D_{min.}$
4′	.04	.46	.21	.24	265	.62	.16
6′	.04	.68	.53	.76	167	1.23	.34
8′	.04	1.1	.97	1.40	152	1.68	.58
12′	.04	2.1	1.48	2.36	115	1.92	1.08
16′	.05	3.1	1.81	3.05	110	1.80	1.54
32′	.38	4.7	2.92	4.47	152	1.50	2.57

about 0.016*N* solution of potassium bromide. The minimum density also becomes lower the more potassium bromide the developer contains, which means clearer highlights in the direct positive tone reproduction. At the same time, the solarization speed goes down.

As mentioned before, to determine the relation of the density depression to the bromide concentration in the hydroquinone developer we determined its correlation coefficient with its probable error. All the data are given in Table VIII.

For normal exposures the values of the correlation coefficients approach in general the unity value so closely that we may say that A. H. Nietz was justified in his assumption of a straight line proportionality between the density and the logarithm of the potassium bromide concentration in the developer. There are, however, distinct deviations from the straight line proportionality with the higher densities and the shorter times of development and with the lower densities and the longer times of development.

In the region of solarization exposures the results are different. With 4 minutes' development time the straight line proportionality is approached in the lower and in the higher exposures. Between these exposures there is a distinct slight deviation from this proportionality. The deviation increases with longer time of development. At the same time the deviation for the other exposure steps increases also. Beyond 10 minutes' development, however, there is no cor-

TABLE VIII.

Density — log KBr Conc. Correlation Coefficients.

Normal Exposures.

Step: Time of Dev.	1	3	5	7	9	11	13	15	17	19	21	23	25	C.C.
4′	0.94	0.94	0.94	0.97	0.95	0.94	0.93	0.91	0.89	0.86	0.81			$-k$
	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.04	0.05	0.06	0.08			$\pm Q$
6′	0.91	0.92	0.93	0.95	0.96	0.97	0.96	0.95	0.93	0.91	0.89			$-k$
	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.05			$\pm Q$
8′	0.91	0.91	0.93	0.94	0.96	0.97	0.98	0.97	0.95	0.93	0.92			$-k$
	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.02	0.03	0.04			$\pm Q$
10′	0.91	0.91	0.92	0.94	0.95	0.97	0.98	0.98	0.97	0.95	0.94			$-k$
	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.03			$\pm Q$
12′	0.91	0.91	0.92	0.93	0.94	0.96	0.97	0.98	0.97	0.96	0.95			$-k$
	0.04	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.02	0.02			$\pm Q$
16′	0.91	0.92	0.92	0.92	0.94	0.95	0.96	0.97	0.96	0.96	0.97			$-k$
	0.04	0.04	0.04	0.04	0.03	0.02	0.02	0.01	0.02	0.02	0.02			$\pm Q$
22′	0.91	0.93	0.94	0.93	0.94	0.95	0.95	0.96	0.96	0.96	0.96			$-k$
	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02			$\pm Q$
32′	0.77	0.83	0.89	0.91	0.92	0.94	0.95	0.95	0.94	0.94	0.95			$-k$
	0.09	0.07	0.05	0.04	0.04	0.03	0.02	0.02	0.03	0.03	0.02			$\pm Q$

TABLE VIII—*Continued.*
Solarization Exposures.

Step: Time of Dev.	1	3	5	7	9	11	13	15	17	19	21	23	25	C.C.
4′	0.95	0.96	0.96	0.96	0.94	0.93	0.93	0.94	0.95	0.96	0.96	0.96	0.96	$-k$
	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	$\pm Q$
6′	0.96	0.96	0.96	0.95	0.90	0.88	0.88	0.90	0.93	0.93	0.93	0.93	0.94	$-k$
	0.02	0.02	0.02	0.03	0.04	0.06	0.05	0.05	0.05	0.03	0.03	0.03	0.03	$\pm Q$
8′	0.95	0.96	0.94	0.90	0.83	0.71	0.69	0.78	0.85	0.88	0.88	0.90	0.93	$-k$
	0.02	0.02	0.03	0.05	0.07	0.12	0.13	0.09	0.07	0.05	0.05	0.05	0.03	$\pm Q$
10′	0.94	0.93	0.91	0.84	0.70	0.50	0.40	0.56	0.73	0.81	0.82	0.85	0.89	$-k$
	0.03	0.03	0.04	0.07	0.12	0.18	0.20	0.16	0.11	0.08	0.08	0.07	0.05	$\pm Q$
12′	0.91	0.90	0.85	0.77	0.55	0.27	0.22	0.41	0.60	0.73	0.78	0.81	0.86	$-k$
	0.04	0.05	0.07	0.10	0.17	0.22	0.23	0.20	0.15	0.11	0.09	0.08	0.06	$\pm Q$
16′	0.77	0.71	0.73	0.61	0.30	0.04	0.06	0.27	0.50	0.64	0.73	0.78	0.84	$-k$
	0.10	0.12	0.11	0.15	0.22	0.24	0.24	0.22	0.18	0.14	0.11	0.09	0.07	$\pm Q$
22′	0.63	0.65	0.62	0.49	0.19	−0.07	−0.08	0.17	0.49	0.67	0.73	0.77	0.78	$-k$
	0.14	0.14	0.15	0.18	0.23	0.24	0.24	0.23	0.18	0.13	0.11	0.10	0.10	$\pm Q$
32′	0.68	0.68	0.65	0.55	0.32	0.04	−0.11	0.03	0.44	0.68	0.76	0.78	0.78	$-k$
	0.13	0.13	0.14	0.17	0.21	0.24	2.36	0.24	0.19	0.13	0.10	0.09	0.09	$\pm Q$

relation detectable for the middle exposures in Table VIII, which corresponds to the beginning of the first reversal of the solarization.

The physical meaning of this effect is not yet known to us. It does not seem to be contradictory, however, to the regression theory of the solarized latent image. It shows that there is at the threshold value of the first reversal of the solarization a maximum disturbance in the relation between the density and the logarithm of the concentration of potassium bromide in the hydroquinone developer.

A. H. Nietz,[9] determining the intersection point of a family of H. & D. curves, showed that the best criterion for the existence of a common intersection or tie-point is the relation between density and gamma. If this relation for different times of development is a straight line it indicates that the tangential lines through the intersection points of the H. & D. curves meet at a point. With increasing potassium bromide content this point moves downward. Instead of determining the slope of the line representing the relation density: gamma graphically we determined the correlation coefficient and its probable error. The data are given in Table IX for the normal exposures and for the solarization exposures. The data obtained with 4 grams of potassium bromide per liter developer were found to be inaccurate in the solarization region and were omitted.

TABLE IX.

Density: Gamma Correlation Coefficients.

Normal Exposures.

Conc. KBr	0	1/4	1/2	1	2	4	8	16	32	Grams per Liter Dev.	C.C.
	0.99 0.001	0.99 0.05	1.00 0.001	1.00 0.001	0.97 0.01	0.99 0.004	0.99 0.003	0.98 0.01	0.99 0.005		$-k$ $\pm Q$

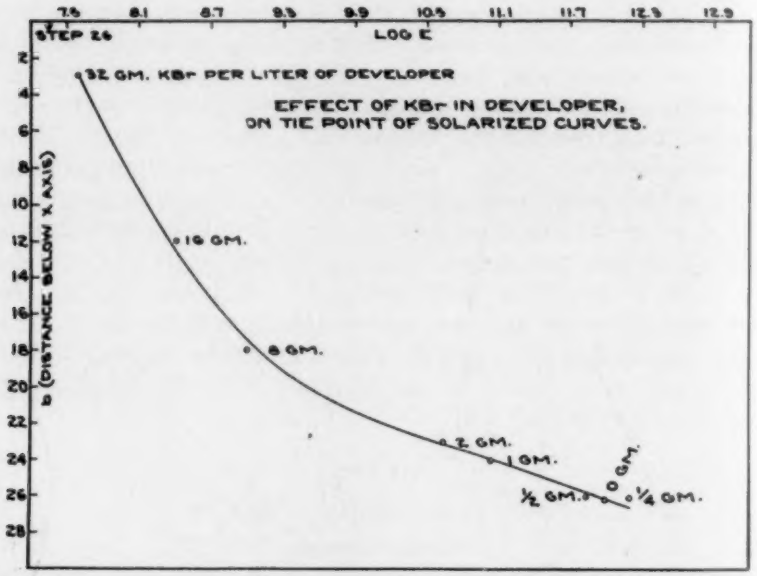
Solarization Exposures.

	0.95 0.02	0.97 0.01	0.99 0.006	0.98 0.01	1.00 0.001	— —	0.91 0.04	0.90 0.04	0.92 0.04		$-k$ $\pm Q$

[9] Loc. cit., p. 41.

It is plain that the correlation coefficient showed, for the normal exposure region, a straight line relation, but not so entirely for the solarization region. By plotting the curves graphically as expected the deviations from the tie-points were noticeable. In Fig. 3 are drawn the approximate positions of the tie-points of the curves obtained with solarization exposures with the different concentrations of potassium bromide in the developer. The log E axis is drawn at the top of the diagram and represents units beyond those given

FIG. 3.



in Fig. 1 and Fig. 2 on account of the fact that the tie-points fall beyond the exposure region below the log E axis. With increasing potassium bromide content the tie-point goes upward to the log E axis, which is just in the opposite direction of the move of the tie-point of the curves obtained with normal exposures. At the same time the tie-point moves toward the origin of the coördinate system, which does not mean that the solarization speed increases, but is caused by the increased solarization contrast.

Summary.—An investigation has been made of the development of the solarized latent image with *p*-amino-phenol, pyrogallol and hydroquinone developer without potassium bromide, and with a series of hydroquinone developers containing potassium bromide from 0.002*N* to 0.269*N* solution. These developers represent a series with different reduction potentials. The investigation was restricted to a pure silver bromide emulsion.

It was shown by the application of the Bravais-Pearson method of determination of the correlation coefficient that A. H. Nietz' straight line proportionality between density and the logarithm of the potassium bromide concentration holds in general for normal exposures, but that in extreme cases of exposure and development, deviations from the straight line proportionality are detectable. This proportionality holds only in a limited way for the solarization region. At the threshold of the first reversal of the solarization there is no correlation at all.

The criterion that a family of curves has, or has not, a tie-point was investigated by the determination of the correlation coefficient between density and gamma. It was shown that the tie-point of the solarization curves moves toward the origin of the distance/log *E* axes with increasing content of potassium bromide in the developer.

Ozone in the Upper Atmosphere and its Relations to Meteorology. G. M. B. DOBSON. (*Nature*, May 2, 1931.) Within the last decade the study of ozone in the atmosphere has been pursued with assiduity and success. Any résumé of the products of the research, such as this discourse before the Royal Institution, is welcomed.

About ten years ago Fabry and Buisson demonstrated the presence of ozone in the high regions of the atmosphere and devised methods for the measurement of its quantity. "If the various gases of the atmosphere were all separated from each other and brought to a layer uniform in density at normal temperature and pressure, the thicknesses of the layers of different gases would be given as follows:

Gas.	Nitrogen.	Oxygen.	Argon.	Carbon. Dioxide.	Neon.	Helium.	Ozone.
Thickness.....	6.2 km.	1.7 km.	76 m.	2.4 m.	10 cm.	3.2 cm.	3 mm."

Even this small amount of ozone has so strong an absorption band in the ultraviolet as to keep practically all solar radiation of wave-length shorter than 3000 A. from reaching the surface of the earth. Indeed it absorbs about 6% of the incident solar energy, thus lessening the possibility of sunburn. Another effect of this absorption is the possession by the high regions of the atmosphere of a temperature higher than that of lower regions. This elevated temperature accounts for the abnormal audibility of sounds from explosions at distances from the origin amounting to 200 km.

Spectroscopic means are used for determining the quantity of ozone in the atmosphere. "In practice it is not convenient to measure the absolute intensity of one wave-length, but we measure the ratio of the intensities of two adjacent wave-lengths, chosen so that one is strongly absorbed by ozone while the other is but little absorbed. By this means we largely eliminate changes due to haziness in the lower atmosphere and also changes in the energy emitted by the sun." Photographic methods are being supplanted by more speedy photoelectric measurements.

"A large number of measurements show that the average height of the ozone layer is about 50 km. above sea-level." The quantity of ozone is far from constant either as to time or place. From day to day its amounts may be almost as 1 to 2, while in both hemispheres a maximum occurs in the spring and a minimum in autumn. In the tropics there is relatively little ozone at any season.

Is ozone produced by the disintegrating effect of short solar radiation on oxygen in high atmospheric regions? This view seems to be refuted by the high values of ozone in polar regions and the low values in the tropics. Another suggestion is that there is some connection between the aurora and ozone production. This theory has not yet won acceptance. In any case there is a fairly well established relation between the meteorological conditions in the upper troposphere and lower stratospere and the quantity of ozone present. G. F. S.

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

WIDE ANGLE HIGH SPEED LENS.

HALL OF THE INSTITUTE,
PHILADELPHIA, February 1, 1928.

No. 2882.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Wide Angle, High Speed Lens invented by Dr. Frank E. Ross, of the Yerkes Observatory, Williams Bay, Wisconsin, reports as follows:

This is a wide angle doublet lens designed to cover a wide field with flatness of field, with freedom from distortion and flare, corrected for astigmatism and for both chromatic and spherical aberration.

This objective is designed for astronomical work and is of the type that includes two spaced components each of which may be a compound lens, one element being positive and the other negative.

The United States patent shows two combinations of lenses that meet the requirements. Figure 1, made from a drawing in the patent, shows one form in which the negative lens of the doublet is on the left and is the front lens of the telescope.

The three parts of this component are in contact and consist of L', a biconvex lens of highly refractive flint glass, a biconcave lens, L^3, of the same, and between them a positive meniscus lens, L^2, of crown glass of low refractive index. The positive component of this doublet includes a positive lens L^5, of barium crown glass and a negative lens, L^4, of glass having a much lower index of refraction.

Wideness of field is secured by making the components of considerable thickness and the inventor finds that the errors are best compensated by placing this thickness in the meniscus lens of the negative component.

In order to secure a flat field free from distortion, over a fairly wide angle the positive lens should be thick also and the inventor finds that the sum of the thicknesses of the two components must be at least one eighth of the equivalent focal length. The glass of the lenses is:

L'	Dense Flint
L^2	Silicate Crown
L^3	Dense Flint
L^4	Telescope Flint
L^5	Barium Crown

This objective will cover an angle of 60° working at F/7.0.

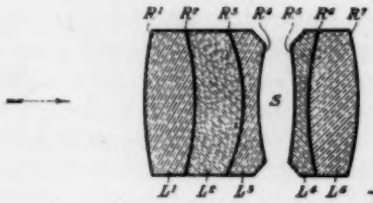


FIG. 1.

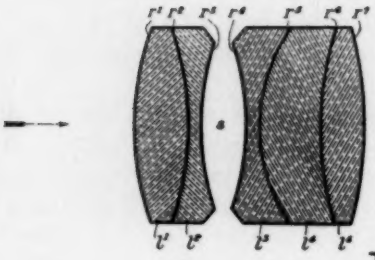


FIG. 2.

Figure 2 shows a form of doublet preferred by the inventor. In this form the position of the components is reversed with respect to Fig. 1, the positive component being in front. The glass used for the lenses is the same as that used in the lenses of Fig. 1.

Doctor Ross submitted three lantern slides made from photographs taken at the Yerkes Observatory with a 3-inch lens, having a focal length of 21 inches. These represent a part of the milky way in the constellation Monoceros, Pleiades

and the well-known Orion nebula. These slides cover a sky area almost 20° square and close examination of the star images shows them to be usable almost to the edge of the plates.

The practical application of the Ross Lens has proved that the extent of field covered is much greater, definition is better and there is shorter exposure.

The United States Patent on this lens has twelve claims of which the last is:

"An objective corrected for distortion and curvature of field and covering a wide angle and comprising two spaced components, one consisting of a positive lens of high refractive index and a negative lens of low refractive index in contact with each other, and the other consisting of three contacting lenses, the inner lens being negative and the outer positive and the central lens of the component being in the form of a positive meniscus, the inner and outer lenses being of the same glass of high refractive index and the central lens being of a glass with a refractive index less by .10 than that of the other lenses of said component and the central lens having a thickness greater than the space between the components and also greater than the sum of the thicknesses of the other two lenses of said component, both Gauss points of said objective being within the objective."

In consideration of his marked contributions to astronomy in the design of wide-angle astrographic lenses of exceptional speed and definition, THE FRANKLIN INSTITUTE awards its JOHN PRICE WETHERILL MEDAL to DOCTOR FRANK E. Ross of the Yerkes Observatory, Williams Bay, Wisconsin.

PROCESS FOR THE DISINTEGRATION OF WOOD.

HALL OF THE INSTITUTE,
PHILADELPHIA, December 5, 1928.

No. 2895.

The Franklin Institute of the State of Pennsylvania acting through its Committee on Science and the Arts, investigating the Process and Apparatus for the Disintegration of Wood and the Like, and the Process of Making Boards

from this Disintegrated Wood developed by Mr. William H. Mason, of Laurel. Mississippi, reports as follows:

Masonite is a product made from wood disintegrated into its fibers and then pressed into insulation board, or into harder and denser masses of such a character as to form a substitute for wood. The wood which is disintegrated may be saw mill waste, such as slabs, board ends, etc., or the waste resulting from lumbering, such as branches and so forth, which are trimmed from felled trees. The two parts of the process are distinct and are covered by separate patents—United States Patent No. 1,578,609 granted to William H. Mason on March 30, 1926 for a "Process and Apparatus for Disintegration of Wood and the Like" and United States Patent No. 1,663,506, also granted to Mr. Mason for "Integral Insulating Board with Hard Welded Surfaces."

The first part of the process of manufacture can best be described by reference to the figures given in the patent first referred to, which are shown in Plate I. Fig. 1 of this Plate shows a vertical section of a container *10* to withstand high pressure and provided with heat insulation. The wood to be used in the process is first reduced to small chips of uniform size and then introduced into container *10* through hopper *30* and valve *18*, which is operated by steam piston *22*. When the container, or gun as it is called, has been filled with chips, high pressure steam is introduced from pipe *34* through pipes *36* and *38*.

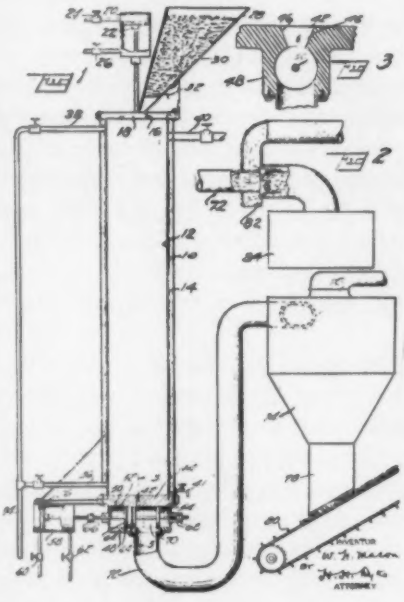
After the gun is charged, steam, compressed air or the like, of at least 275 lb. pressure per square inch is introduced into the chamber. It is preferable to use steam at a pressure of from 400 lb. to 600 lb. Where pressures over 275 lb. and under 400 lb. per square inch are used with wood which is not readily disintegrated, it is preferable to use successive steps to secure thorough disintegration. While it is possible to use agents other than steam, such as compressed air, steam is the best, at least at the beginning of the operation on account of its softening action on the wood.

After the pressure has been maintained for a sufficient time to permit the gases under pressure to penetrate the wood, and especially to secure a substantial balance between the internal and external pressures and also between the

temperatures within and around the wood, and to heat the moisture within the wood to a temperature which will cause it to turn to steam upon releasing the pressure, the pressure is released by opening balanced piston valve *52* which permits the mass to flow through the opening *42*. This opening is shown in detail in Fig. 3 and consists of a slot of uniform width at the top, tapered to a narrower width at the bottom.

When the valve is first opened the expansion of the high pressure steam in the gun discharges the mixture through

PLATE I



this slot opening, the action of which is first to compress the wood fibers and then to allow them to expand through the explosion of the steam or gas.

The patent claims that the compression of the wood through this outlet is one of the features of the design which makes it successful.

After the wood is discharged from the gun it is carried up to a cyclone as shown in Fig. 1, from which it is discharged on a carrier and conveyed to storage bins or to an apparatus

for the further manufacture of the artificial wood or insulation board.

Figure 2 shows a modification of this arrangement whereby the exploded material is discharged into a pipe carrying water, *82*, and from this into a larger pipe and also into container, *84*.

The disintegrated wood described above is capable of being formed into several products, of which the principal ones are insulation board and artificial lumber.

The method of forming the disintegrated wood into the final products is the subject of the second patent, No. 1,663,506. The disintegrated wood is made into felted sheets from a water bath in a manner common to the usual wood pulp and paper making processes. The excess water in the felted sheets is removed by passing them between squeezing rollers, or by drying. The sheets are then cut into convenient lengths and placed between steam heated upper and lower platens of a press. The effect of the combined heating and pressure is to produce a substance having a smooth surface, reduced in thickness and having an inner portion, the hardness of which depends upon the length of the treatment.

The temperature of the platens, amount of pressure employed and length of treatment are all determining factors in the results obtained, and whether or not insulation board or "Presdwood" is the final product.

Twenty-one claims are allowed in patent No. 1,578,609 of which the fourteenth is as follows:

"Apparatus for the disintegration of ligno-cellulose material comprising a high pressure cylinder, a valved inlet for charging said cylinder, connections for introducing elastic fluid under high pressure into said cylinder, a valve chamber adjacent to the base of said cylinder and extending transversely thereof, a narrow outlet of gradually diminishing section provided in the base of said cylinder and communicating with the valve chamber, a shaft extending axially through the valve chamber, and a balanced slide valve within said valve chamber on the shaft comprising two pistons substantially separated from one another, whereby a large expansion area is provided immediately upon the discharge of the material from the high pressure cylinder through the

narrow outlet, and means for actuating the valve shaft to open and close the outlet valve."

Seven claims are allowed in patent No. 1,663,506, of which the sixth reads as follows:

"Process of forming integral fiber products comprising adjacent portions which are respectively of high density and high porosity, which comprises applying heat and pressure to a body of wood or woody fiber containing practically all the original wood or woody material until welding or coalescing of the fibers into permanent relation has extended therein to a material extent but not therethrough, and releasing the pressure whereby the portion to which welding or coalescing has not extended is permitted to expand into highly porous state."

Mr. Mason, however, states that long fiber pulp can be made from this material which will have an advantage over sulphide pulp in that the resin remains in the pulp, free from volatile oils which are carried off with the steam and that this makes it unnecessary to use sizing in the final paper or pulp in order to make it ink proof. This last use, however, is not certain and the Institute's Committee has been unable to determine that any such disintegrated wood is used to any great extent for paper.

An examination of the prior art discloses the fact that a patent was issued to A. S. Lyman in 1858, No. 21,077. This covers an apparatus in which the wood to be disintegrated was introduced into a cylinder and subjected to the action of steam under pressure. The material, however, was discharged all at once by a trip trigger. This resulted in several severe explosions in which some of the operators were killed and the process was abandoned. Apparently Mr. Mason's process has been made successful by discharging the material through the small port previously described and also by the fact that he has been able to obtain apparatus that will give steam with a pressure up to 1200 lb. and also apparatus which will handle pressures of this order.

It is interesting to note at this point that the Mason Fiber Company was the first manufacturing company in this country to use boilers in excess of 1000 lb. and to use the steam for process work.

Insulation board is apparently of the same general char-

acter as Celotex. "Presdwood" provides a very acceptable substitute for wood in large sheets. These products afford a new source of supply of insulation board and wood substitutes.

The process is novel, in that it reforms wood waste from a condition in which it cannot be used as lumber into thin sheets of large area which provide a substitute for natural wood.

That the product is of great commercial value is illustrated by the fact that at the present time it is being manufactured at the rate of 30,000,000 square feet per year. At the present time an addition is being made to the plant which will double this output.

In consideration of the development of his process for the successful use of wood waste, THE FRANKLIN INSTITUTE awards its JOHN PRICE WETHERILL MEDAL to MR. WILLIAM H. MASON, of Laurel, Mississippi.

PENDULUM HARDNESS TESTER.

HALL OF THE INSTITUTE,
PHILADELPHIA, June 6, 1928.

No. 2872.

The Franklin Institute of the State of Pennsylvania acting through its Committee on Science and the Arts, investigating the Pendulum Hardness Tester invented by Mr. Edward G. Herbert, of Manchester, England, reports as follows:

The subject of this investigation is a new method of measuring the hardness of materials, together with a new form of apparatus by which this method may be carried out.

The method consists of making an indentation in the surface of the material under test, in so far resembling older methods. But the manner of making the indentation and of measuring its amount are distinctly new.

The initial indentation is made by a small hard ball, normally of 1 mm. diameter, to which is applied a fixed weight, usually of four kilograms. The weight consists of an inverted U-shaped piece of metal, to which the ball is fastened, the proportions being such that the center of gravity of the whole structure may be adjusted so as nearly to coincide

with the center of the ball. In other words, the instrument constitutes a pendulum having large moment of inertia and very short length, adjustable so as to bring the period of oscillation to ten seconds per single swing, when the ball rests upon a glass surface. If the instrument is set upon a surface of softer material, more or less indented by the ball, the behavior of the pendulum, when started swinging, is effected in two ways: first, its swings are dampened; second, its period of swing is shortened.

Experimental research has shown that the damping effect and period of oscillation constitute two distinct means of measuring the hardness of the material under test, the results obtained by the two methods being in general similar, but not identical. The test referring to the damping effect is known as the Scale Hardness Test, that referring to the period of oscillation, as the Time Test.

With this brief outline of the principles of the test in view, a detailed description of the instrument follows:

DESCRIPTION OF THE INSTRUMENT.

Plate I is from a photograph of the device in use and shows how it can be applied to the measurement of the hardness of bodies of irregular shape; in this particular case, the tooth of a bevel gear, held in a special chuck that permits of easy levelling.

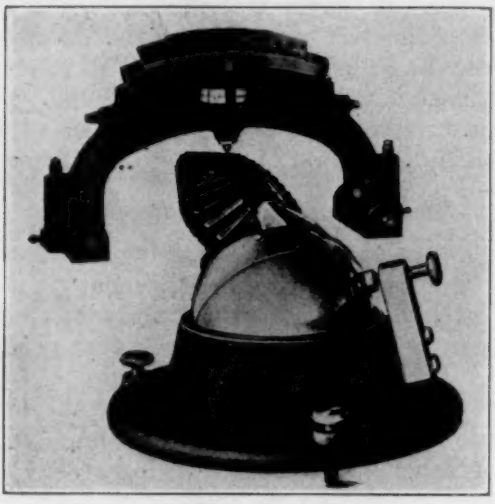
Details of construction of the device are shown in Plate II which is made from drawings in U. S. Patent No. 1,608,655, granted November 30, 1926, to Edward G. Herbert, of Levenshulme, England, on an application filed February 15, 1923.

In Fig. 1 of this Plate, which is a front elevation, *a* is the ball, or test member, upon which the pendulum rests, *b* the weight member, and *c* the piece of material under test. A tripod *e* carries a table *d*, the height of which can be adjusted for supporting the test piece. The weight member *b* is in the form of an arch, the two halves being alike in shape and weight. This makes it possible to balance the member on the ball *a* as a fulcrum. In order to ensure this balance, screw plugs b', b^2 and b^3 are provided by means of which an accurate balance is obtained and the center of gravity of the

mass is controlled. When there is a condition of neutral equilibrium, the center of gravity of the yoke coincides with the center of gravity of the test member, i.e. of the ball upon which the device rests.

As a means of further adjusting the height of the center of gravity of the instrument, there is provided a small disc-shaped weight, b^4, with graduations upon its circumference, and mounted upon a vertical screw. The purpose of this weight is to raise or lower the center of gravity by a known amount; whereas the screws b^2, simply furnish the means of

PLATE I



adjusting to a desired period of oscillation. For testing steels and similar metals generally, the center of gravity is adjusted to 1/10 mm. below the ball center; for softer materials this distance is sometimes increased; while in exceptional cases it may sometimes be decreased.

In order to measure the extent of the swing of the instrument, there is provided an inclinometer, shown at the top of the pendulum in Fig. 1, of Plate II. This device consists of an arc-shaped glass tube *f*, nearly filled with liquid, after the manner of a spirit level, and having a graduated scale *i* with divisions from 0 to 100 fastened above it, conveniently

for reading the position of the bubble. A smaller spirit level *j*, Fig. 2, fixed at right angles to the main tube, shows when the principal plane of the instrument is correctly adjusted in a vertical position.

Thirteen claims are allowed in the patent issued to Mr. Edward G. Herbert, of which the twelfth may be quoted as follows:

"In means for testing the hardness of metals or other solid materials, a spherical test member of hard substance,

PLATE II

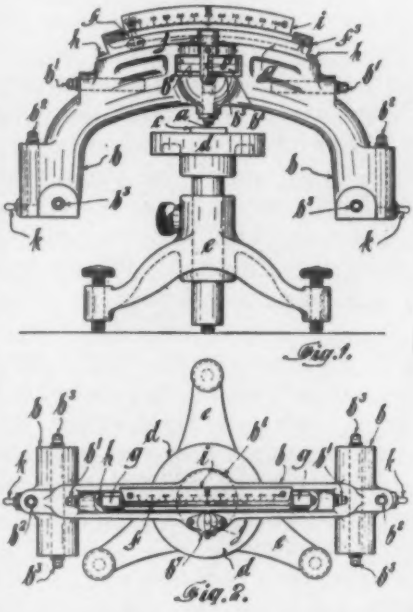


Fig. 1.

Fig. 2.

a weight member in the form of an arched metal body with downwardly extending extremities the parts of the weight member to right and left of its medial line being a facsimile of each other in shape, size and weight, means for attaching said test member to the weight member at a point central to the length and width of said weight member, said weight member having a centrally disposed opening formed in it, a fixed spindle with screw thread of millimeter pitch in said opening, a circular metal disc on said spindle, adapted to move up and down the spindle on being rotated and thereby

vary the position of the centre of gravity of the weight member, an inclinometer secured to the top of the weight member and comprising a glass tube partly filled with liquid and having an air bubble, and also comprising a plate with divisions and numbers marked on it, said divisions and numbers representing respectively the degrees of deflection out of the vertical and the hardness numbers of varying materials, as set forth."

PRIOR ART.

Since hardness is a quality that has not yet been accurately defined, we have no universal unit of measurement, by which it may be expressed. One of the oldest methods of determining hardness is that of abrasion, in which two bodies are rubbed together, and the one worn away least is considered the harder of the two. A variation or refinement of this method is that of scratching one body with another.

These methods have given rise to a relation known as Moh's scale of hardness built on ten different materials, each of which has a number, beginning with 1 for talc and ending with 10 for the diamond. Each mineral on the list would scratch the one next below it. Ordinary glass is number 7.

Mr. Herbert, the inventor of the Pendulum Hardness Tester, believes that his method has certain advantages over these and other previous methods, which make it readily applicable in certain cases where the others are difficult to use, and that his instrument will measure certain qualities, especially of metals, that cannot be directly determined by any of the other instruments.

Method of Making the Pendulum Tests.—Hardness may be measured in two ways by the pendulum tester, the first designated as "Time Hardness" and the second as "Scale Hardness." These two methods are in general agreement as to the relative hardness of any given group of materials, though they do not exactly coincide, and Mr. Herbert claims as a distinct advantage of his method that the relation between the two throws new light upon the physical properties of metals.

The method generally employed is that of measuring the time of oscillation of the pendulum, and its results are ex-

pressed as Time Hardness Numbers. To carry out this test, the pendulum, after having been checked for adjustment, is placed gently upon a smooth, level surface of the test material, and caused to oscillate through a small arc, of about 10–15 divisions of the inclinometer. Resting upon a piece of glass the pendulum, properly adjusted, makes a single swing in ten seconds. Resting upon material softer than glass, as ordinary steel, for instance, the period of oscillation is shorter than ten seconds, and constitutes a definite measure of the hardness. The number of seconds for 10 single swings constitutes the Time Hardness Number of the material under test.

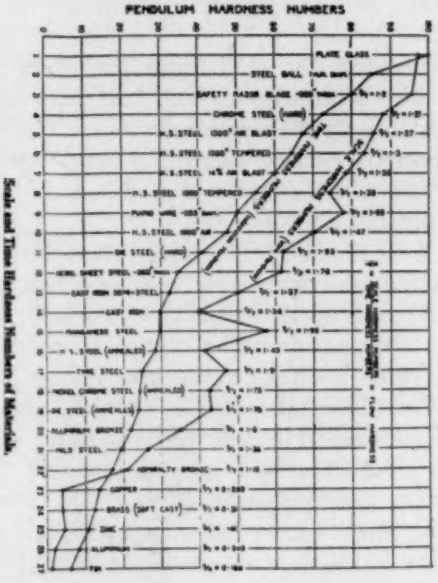
Results obtained by this time hardness test are very similar to results from the Brinell test into which they are readily convertible by a simple formula. The test is quickly made, and may be carried out on a single specimen of thin sheet metal, to which the older methods are only with difficulty applicable.

The second method of performing a test with the Pendulum Tester is known as the Scale Test. In this test, the pendulum, as before, is placed upon a flat level surface; then tilted till the bubble in the inclinometer comes to zero, and released. On a hard surface such as glass, the instrument will swing over till the bubble comes almost to 100, about to 97 ordinarily. If placed upon softer material, and handled in this way, the damping effect will be greater, and the instrument will come to rest some distance short of the 100 mark. That point upon the scale where the first swing ends is called the Scale Hardness Number and constitutes another measure of hardness.

Plate III, taken from tests made from Mr. Herbert's curves, shows two series of tests the scale and time hardness of a number of different samples of the metals, covering the range between tin, on the one hand, and the hardest steels on the other. The two series of figures are in general accord, but are not identical, and Mr. Herbert believes that the relation of the Scale to the Time Hardness has a special significance as to the quality of the material under test; but the Institute feels unwilling to express an opinion as to this point. Attention may be called, however, to one quite

striking point shown in the Plate; the relative behavior of cast iron No. 14 and manganese steel, No. 15. Both show about the same hardness measured by the time test, as also by Brinell test, but by the scale test the manganese steel is very much higher. The ratio of the scale hardness to the time hardness is higher for this manganese steel than for any of the other steels shown, which Mr. Herbert believes is definite indication of its extreme resistance to wear and abrasion, as in railroad frogs and crossovers.

PLATE III



While the complete theory of the pendulum hardness test is not fully understood, it may be very broadly outlined as follows: When the pendulum is placed upon a test piece, the ball indents the surface slightly, just as in the older methods of testing. When it is set swinging in this indentation, its period of oscillation is shortened and hence the time required for a single swing is a measure of the depth of the indentation. On this depends the Time Hardness Test.

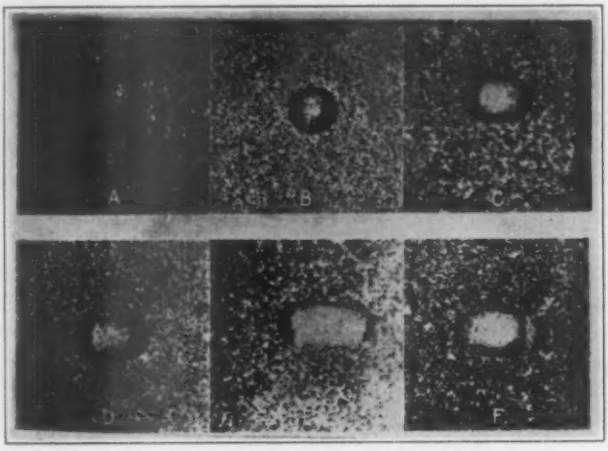
Similarly it is quite obvious that when the pendulum is tilted far over to one side and released, its swing is dampened by the amount of energy absorbed in elongating the indent.

The softer the material, the deeper the indentation, the greater the energy of elongating it, and the shorter the swing. Hence the Scale Hardness Test.

The distinction between the two tests may be roughly described in this way; the time test measures indentation hardness, while the scale test is largely a measure of resistance to flow.

In Plate IV are shown some micro-photographs of the impression made by the pendulum tester upon a surface of annealed carbon steel.

PLATE IV



In Fig. *A* the pendulum was placed upon the specimen and removed, without swinging.

In Fig. *B* a normal time test was carried out, by placing the pendulum on the specimen, and causing it to swing through a small angle of 10 or 15 scale divisions. The time required for ten single swings was 22 seconds, and a slight elongation of the indent may be noticed.

In Fig. *C* the pendulum was placed level upon the specimen with the inclinometer reading 50, and then tilted till it read 0, and removed without swinging.

In Fig. *D* it was placed and tilted to zero as in *C*, and then allowed to swing back, coming to rest at 45. This is the normal scale test.

MEASUREMENT OF WORK HARDNESS.

It has long been known that practically all metals when subjected to working, such as rolling, drawing or hammering, become hardened, and a very valuable characteristic of the pendulum tester is its ability to develop this "work hardness" and practically at the same operation, measure it. To do this it is merely necessary to swing the pendulum slowly the full scale length a few times, and then to make either a time or scale test without removing it from the indent.

The pendulum may be slowly rocked back and forth as many times as necessary, but in most cases three or four such swings are sufficient to develop the maximum hardness, and continuation of the process may even show a slight apparent falling off.

The value of this work hardening test depends on the fact that a work hardness test made upon a given piece of material, such as for instance, an annealed steel rail, checks very closely with a simple hardness test made upon the same specimen after it has been work hardened as by having trains pass over it in actual use.

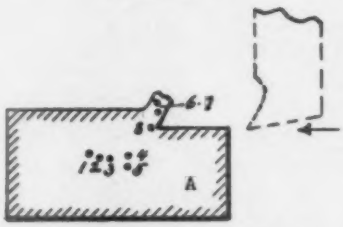
Since the wearing qualities of steel subjected to continual hammering or rubbing are dependent upon the hardness developed by this working process, the ability of the pendulum tester readily to determine the work hardness capacity of a sample of steel is of distinct advantage. To ascertain the work hardness capacity by means of the usual methods of testing, the specimen must be worked, by hammering, etc., as a distinct operation, and then tested; whereas the pendulum tester both develops and measures the work hardness practically at one operation.

Plate IV, Fig. *E*, shows the impression made by resting the pendulum upon the specimen, and slowly tilting it from 100 to 0 and then removing. This single rolling of the metal has been sufficient to develop a very marked hardening, for when the pendulum was released at 0 and allowed to swing it came to rest at 70, leaving the mark plainly shown in Fig. *F*.

Plate V shows a test made by the Institute with a pendulum hardness tester, and taken from a similar test described by Mr. Herbert. A piece of ordinary mild steel

bar represented by *A*, about 3/16″ thick, was placed in a planer and a rather heavy cut of about 1/16″ depth was taken as indicated at the upper right hand corner. Time hardness tests were then taken at the points noted. The hardness of the unworked steel at points 1–5 showed as follows: 20–21–20–26–23. At points 3, 4 and 5 the material was work hardened, by slowly rocking the pendulum from side to side two or three times, and retested. The hardness now found was 30–35–31, which shows at once the effect of working the metal. Tests 6 and 7 were made upon the

PLATE V



Test Number	Initial Test	After Working
1	20	
2	21	
3	20	30
4	26	35
5	23	31
6	33	
7	31	
8	33	

actual chip severed by the tool from the main body of steel and therefore subjected to the maximum of working. The hardness here was found to be 33 and 31; while at point 8, just ahead of the cutting edge, where the metal had begun to flow, the hardness was 33. The agreement between the work hardness produced by the hardness tester and by the actual tooling in the planer is very striking.

A great deal of interesting and enlightening work has been done by Mr. Herbert on the general question of work hardening of metals and on the effect of heat and working combined. To fully describe these tests would be beyond the proper scope of this report, but it is believed that they have added

to our useful knowledge of these vital properties of engineering materials.

CONCLUSION.

The Institute feels that in two respects the instrument under consideration is superior to other existing hardness testers. First, it appears to be better adapted to measuring the hardness of a thin sheet of metal; second, it appears to be the only instrument capable of developing and measuring the hardness produced by the working of a material.

In consideration of his development of the Pendulum Hardness Tester and its practical application, and his contribution to the general knowledge of the hardness of metals, THE FRANKLIN INSTITUTE awards its EDWARD LONGSTRETH MEDAL to MR. EDWARD G. HERBERT, of Levenshulme, England.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

DESIGN OF INDUCTANCE STANDARDS.

A report, which will be published in the August number of the Bureau of Standards *Journal of Research*, discusses the design of standards of inductance for both laboratory and plant use. The paper deals with three distinct classes of reactors for different kinds of applications. The first class includes coils of wire which are wound on nonmagnetic cores to have definite values of inductance, and to serve as laboratory standards by which other inductance apparatus is checked. The second class includes very large inductance coils, commonly called current-limiting reactors, which are used in power plants to prevent the destruction of generators and other apparatus by short-circuits. The third class of reactors differs from the other two in having the copper coil wound around an iron core having an air gap in its magnetic circuit. These iron-core reactors are used in various branches of electrical engineering.

Certain useful general relations apply to these three kinds of reactors, and may be used to advantage in connection with their design. A list of these relations, a number of which have not been published hitherto, is given. They form the basis for a convenient and rapid method for the design of inductance standards, which is believed to be the first design procedure of this kind to be published. To obtain a given value of inductance while keeping the resistance below a certain permissible value, meanwhile using the minimum amount of conducting material for the coil, requires a particular optimum geometric *form* of coil. A form originally proposed by Maxwell, first used for standards of inductance by Wien in 1896, has been widely used. The less generally known modification of Maxwell's form described by Shawcross and Wells in 1915, is slightly better than Maxwell's and is used in the design procedure of the paper.

* Communicated by the Director.

With the design curves, which are given for both English and metric units, one can see at a glance the weight of copper and the size of the coil to obtain a given time-constant, on the basis of round wire having ideal insulation of zero thickness. The diameter of the wire is also shown, on the assumption that the value of inductance desired is one millihenry, and an auxiliary curve gives values of a factor by which this diameter is to be multiplied to obtain the diameter for any other inductance in the range between one millihenry and one henry. Since actual insulation takes up space, one must use a larger coil of wire of larger diameter and greater weight than the values given by the curves for ideal insulation. The procedure for the revision of the ideal values to those for wires having a specified kind of insulation is simple and requires only slide-rule calculations.

Other subjects relating to standards of inductance, which are briefly discussed, include: Suitable materials for the spool on which the wire is wound, method of adjusting the standard, and the best method for assembling inductance coils in sets.

The general theorems which underly the design procedure just mentioned are then used to show how small model coils may be employed to predetermine the self inductance and mutual inductance of large current-limiting reactors, as a check on existing methods of design. It is shown that the translational force between two reactors during short-circuit, which sometimes amounts to many tons, may be determined by measuring the force between two small-scale models. The remarkable fact is easily demonstrated that if the model coils have the same number of turns as the corresponding full-size coils, and are correspondingly placed, the force between the model coils will be the same, for a given current, as that between the full-size coils.

The last section of the paper deals with the iron-core reactor. The reasons for the use of an airgap in the core are given, and it is demonstrated that for a given maximum flux density in the core the desirable minimum power factor is obtained when the length of the gap is such as to make the copper loss equal to the iron loss. The use of model iron-core reactors is proposed, both as a check on present methods of design and as an independent basis of design. In conclusion,

some interesting facts about iron-core reactors are quoted from a recent paper by F. Emde of Vienna.

ELECTRICAL PROPERTIES OF FOREIGN AND DOMESTIC MICAS.

A number of samples of mica, fairly representative of the major sources of the world's supply, have been tested at the bureau for dielectric constant, power factor, dielectric strength, and ability to withstand elevated temperatures. These micas consisted of ruby and green muscovites, biotite and phlogopite, obtained from Africa, Argentine, Brazil, Canada, Guatemala, India, Madagascar, and the United States. It was the purpose of this investigation to determine the average values of power factor, for example to be expected from the various grades of mica as well as the normal variations from these averages which must be expected in commercial lots of mica. The data should be of interest to the producers of mica as well as to those who are called upon to set up specifications for the purchase of this material. The results of these tests, which will be described in full in the August number of the Bureau of Standards *Journal of Research*, are as follows:

For clear ruby muscovite, in the frequency range from 100 to 1,000 kilocycles, a dielectric constant of 7.2 and a power factor of 0.02 per cent. may be expected, on the average. Individual samples may be expected to vary, on the average, from these values by $\pm$ 0.3 in dielectric constant and $\pm$ 0.01 per cent. in power factor. Within this frequency range the dielectric constant and power factor of clear ruby muscovite are apparently independent of frequency. The presence of stains and inclusions so seriously affects the power factor as to render such stained micas unsuited for radio purposes. The power factor of phlogopite is also found to be so high as to render it unsuited for use in radio circuits. The power factor of both stained muscovite and phlogopite is shown to be a function of the frequency used in the test.

The dielectric strength of mica is found to be relatively unaffected by the presence of air bubbles, and but slightly affected by the presence of moderate amounts of stains in the form of metallic oxides. Curves showing the average

dielectric strength of various classes of mica as a function of the thickness of the specimen, are included in the report.

With but two exceptions, all of the micas investigated were unaffected by an exposure to a temperature of 600° C. for 30 minutes. Above that temperature the phlogopites withstood heating better than the muscovites.

In none of these tests was it possible to make any distinction between the various micas based solely on the geographical origin of the samples.

RIPENING OF PHOTOGRAPHIC EMULSIONS.

The literature on photographic emulsions, except for a few recent articles, gives the impression that an emulsion must be "ripened" to its full sensitivity before washing. At the bureau it has been found that actually it is not only possible but desirable to digest the emulsion after washing, thus multiplying the speed by a factor of 20 or more in many cases. Fast emulsions without ammonia must be made in this way. An article which will appear in the August number of the Bureau of Standards *Journal of Research* describes an extensive study of the after-ripening process in the photographic emulsion laboratory and gives emulsion formulas and experimental methods in full detail. After-ripening by digestion was studied with respect to the effects of (1) ripening before washing, (2) temperature, (3) bromide or chloride ion concentration, (4) hydrogen ion concentration, (5) gelatin-silver halide ratio, (6) make or batch of gelatin, (7) addition of known sensitizing materials, and (8) proportion of iodide in the silver halide. The results can be best explained by the theory that the photographic effects are the result of a chemical reaction or reaction similar to that of silver bromide with allyl thiocarbamide, although with the gelatin used in the experiments there were distinct quantitative differences from the results with pure sensitizers like allyl thiocarbamide. If the emulsions were not digested sufficiently before coating, there was a slow after-ripening of the finished plates, generally similar to that during digestion. Analytical determinations of the change in bromide ion concentration and in non-halide silver, during after-ripening, indicate that there was chemical re-

action roughly parallel to the photographic changes, but probably only a small part of the products of the reaction or reactions are photographically important.

LUBRICATION OF CLOCKS AND OTHER DELICATE MECHANISMS.

In coöperation with the Clock Manufacturers Association of America, the bureau has been investigating the lubrication of delicate mechanisms, such as clocks and watches, aeronautical instruments, etc. The importance of this subject has increased greatly with the increase in number and diversity of these instruments. Many are ruined and much money is lost by unsatisfactory lubrication.

The following suggestions are offered as criteria by which to judge suitability of a lubricant:

1. Availability.
2. Chemical stability.
3. Corrosive action on metals.
4. Tendency to escape from pivots by spreading or by evaporation.
5. Friction reducing properties.
6. Temperature-viscosity characteristics including the properties of the oil at low temperatures.

The oil from the head and jaw of the porpoise and the blackfish has for many years been found to conform satisfactorily to most of these requirements, but at present cannot be supplied in sufficient quantity to meet the demands; the price of the oil now being in the neighborhood of $125.00 per gallon. The other fatty oils in general, such as olive oil, cotton seed oil, etc., are, as prepared at the present time, objectionable on the grounds of chemical instability, corrosive action on metals and the relatively high temperature—not much below 0° C.—at which they solidify. The petroleum oils are open to the objection that they have a tendency to escape from the bearings by spreading out over the plates and bridges of the timepiece. They are also less effective in reducing friction than fatty oils under conditions such as those encountered in timepieces.

The most promising suggestions which have been put forth to overcome the above difficulties are as follows:

1. To increase the supply of porpoise jaw oil by establishing fisheries or, more properly, whaling stations, and by artificially propagating porpoises and blackfish.

2. To prevent the deterioration of olive oil, sperm oil, or some other plentiful fatty oil by the use of more scientific methods of preparation or by incorporating a chemical into the oil to increase its stability.

3. To synthesize an oil which would be free from the limitations of fatty oils and mineral oils alike.

4. To use mixtures of petroleum oils and fatty oils, in order to obtain the benefits of the superior qualities of both classes of lubricants.

5. To treat the plates and bridges of the timepieces with a chemical which would prevent mineral oils from spreading, thus permitting the use of these otherwise satisfactory products.

PROGRESS REPORT ON SOIL CORROSION.

Eight years ago the bureau began a study of the relation of soils to the corrosion of pipe materials buried underground. A very large number of specimens of all of the commonly used materials were buried in 47 soils. At approximately two-year intervals representative samples have been removed and the extent of the corrosion carefully determined. Such an examination was made during 1930, and the results, assembled and tabulated, were published in the July number of the Bureau of Standards *Journal of Research*. In general, they confirm the conclusions reached after previous inspections, as reported in Technologic Paper No. 368. Throughout the eight years during which the specimens have been exposed, characteristics of the soil rather than of the ferrous materials have controlled the kind and extent of the corrosion. Because there is a possibility that at later periods differences in the materials will result in appreciable differences in rates of corrosion, the bureau believes that it should not make comparisons of materials at this time; moreover the data now available do not indicate that any one of these is best for all soil conditions. So far, materials which appear best under one soil condition have appeared inferior to some other material in a different soil.

Rates of corrosion vary somewhat from year to year because of settling of the trench in which the specimens were buried, and changes in the supply of moisture. There is no constant relation between the rate at which specimens lose weight and the rate at which the depth of pits increases. Some soils cause the materials to pit badly, but the pitting results in comparatively little loss of weight. In other soils the corrosion is more uniformly distributed over the surface of the material, and a considerable loss of weight occurs with a low rate of penetration. As in most installations of pipe much thicker material is used than is necessary to withstand the pressure of the fluid carried, the loss of weight is not of great importance if uniformly distributed, but the formation of even a few deep pits may be a serious matter.

Rate of pitting, therefore, rather than rate of loss of weight is frequently the best indication of the corrosiveness of a soil. While data to be secured later may indicate relative merits of materials, the data so far obtained are chiefly valuable in connection with the study of field methods for determining soil corrosivity. When these methods are further developed, it will be practicable to make a soil-corrosion survey, from the results of which the owner can tell whether he should use a corrosion-resistant pipe material or apply a protective coating to his line.

EFFECT OF HEAT TREATMENT ON ULTRA-VIOLET TRANSMISSION OF SPECIAL GLASSES.

In a report to be published in the August number of the Bureau of Standards *Journal of Research* data are given which show the relation between the ultra-violet transmissions of two commercial glasses (vita and helio glass) before and after solarization by ultra-violet radiations at ordinary temperatures and also after various heat treatments in the range 200° to 600° C.

It is shown that the highest ultra-violet transmission found for these glasses was obtained after heat treatments at temperatures in the annealing range, that is, somewhat above 500° C. Treatments at higher temperatures cause deformation and some surface deterioration while those at lower temperatures are less effective in rejuvenating the glass, although

treatments at temperatures as low as 300° C. often approximately restored the transmissivity to its initial value on receipt of the glass.

Visible colorations, which on artificial solarization accompany the decrease in transmission of the shorter visible rays apparently disappear completely upon relatively short heat treatments at temperatures no higher than 200° or 300° C. The visible thermo-luminescence accompanying this disappearance of the coloration, and apparently persisting only during the time required for the restoration of the transmission near the visible spectrum, was found to grow more intense and to continue for correspondingly shorter intervals as the temperature of heat treatment was raised.

Even after the visible coloration and thermo-luminescence had disappeared as a result of heating at these low temperatures, the complete restoration of the transmission for the shortest wave-lengths transmitted by these glasses required additional heat treatments near 500° C.

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LIBRARY NOTES.

RECENT ADDITIONS.

American Institute of Chemical Engineers. Transactions 1930, Volume 25. 1931.

ANSCHÜTZ, RICHARD. August Kekulé. 1929. Two volumes.

BAILEY, SOLON I. The History and Work of Harvard Observatory 1839 to 1927. Harvard Observatory Monographs. No. 4. 1931.

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London, Edinburgh and Dublin Philosophical Magazine and Journal of Science. Name Index to the Sixth Series, with an Appendix Containing a Name Index to the Years 1926–1930 of the Seventh Series. 1931.

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SHERMAN, H. C., AND S. L. SMITH. Vitamins. Second edition. 1931.

SIMON, E. D. The Physical Science of Flour Milling. 1930.

STOCKBRIDGE, FRANK PARKER, AND JOHN HOLLIDAY PERRY. Florida in the Making. 1926.

WEHMER, C. Die Pflanzenstoffe. Zweite, neubearbeitete und vermehrte Auflage. Zweiter Band. 1931.

World Engineering Congress, Tokyo, 1929. Proceedings. Volumes 1–39. 1931.

BOOK REVIEWS.

AN INTRODUCTION TO ORGANIC CHEMISTRY. By Roger J. Williams, Professor of Chemistry, University of Oregon. Second Edition. New York, D. Van Nostrand Company, Inc. Copyright 1931, xii + 585 pages. Price $3.50 net.

In addition to the subjects usually presented in an elementary treatise on

organic chemistry, this book contains either chapters or sections devoted to such subjects as the proteins and their related compounds, the terpenes and camphors, the alkaloids, dyes, enzymes, toxins and antitoxins, hormones, and vitamins. This feature renders the treatise of especial value to the biologist and the pre-medical student as well as to persons who wish a comprehensive introduction to this extensive branch of chemistry. Another feature is an appendix on the "Consultation of Chemical Literature," chiefly in its organic aspects. Physico-chemical relationships and industrial applications also receive attention in the text.

JOSEPH S. HEPBURN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 386. Maneuverability Investigation of an F6C-4 Fighting Airplane, by C. H. Dearborn and H. W. Kirschbaum, 25 pages, illustrations, quarto. Washington, Government Printing Office, 1931, price twenty cents.

In order to compare the relative maneuverability of two fighting airplanes and to accumulate additional data to assist in establishing a satisfactory criterion for the maneuverability of any airplane, the National Advisory Committee for Aeronautics, at the request of the Bureau of Aeronautics, Navy Department, has conducted maneuverability investigations on the F6C-3 (water-cooled engine) and the F6C-4 (air-cooled engine) airplanes. The investigation made on the F6C-3 airplane has been previously reported. This report contains the results of the investigation made on the F6C-4 airplane.

Measurements of air speed, angular velocity, linear acceleration, temperature, pressure, and the position of the controls were made for practically all the kinds of military maneuvers required of this type of airplane. Flight path coördinates were secured for most of the maneuvers by means of a special camera obscura developed for this investigation. The results are given in the form of curves, some showing the variation of the measured quantities with respect to time, others, the variation of some maximum quantities with respect to air speed. In addition, all maximum quantities are tabulated.

A comparison of the results with those obtained in the investigation conducted on the F6C-3 airplane shows that: with practically the same speed and control movement, the F6C-4 completed a loop in 10 per cent less time than did the F6C-3; in dives the F6C-3 increased its speed more rapidly than did the F6C-4; and the minimum radius of turn was found to be 135 feet at 61.5 miles per hour for the F6C-4, and 155 feet at 76 miles per hour for the F6C-3.

Report No. 387. The Vertical Wind Tunnel of the National Advisory Committee for Aeronautics, by Carl J. Wenzinger and Thomas A. Harris, 10 pages, illustrations, quarto. Washington, Government Printing Office, 1931, price ten cents.

The vertical open-throat wind tunnel of the National Advisory Committee for Aeronautics is described in this report. The tunnel was built mainly for studying the spinning characteristics of airplane models, but may be used as well for the usual types of wind-tunnel tests. A special spinning balance is being developed to measure the desired forces and moments with the model simulating the actual spin of an airplane.

Satisfactory air flow has been attained with a velocity that is uniform over the jet to within ± 0.5 per cent. The turbulence present in the tunnel has been compared with that of several other tunnels by means of the results of sphere drag tests and was found to average well with the values of those tunnels. Included also in the report are comparisons of results of stable autorotation and of rolling-moment tests obtained both in the vertical tunnel and in the old horizontal 5-foot atmospheric tunnel.

Report No. 388. Investigation of the Diaphragm-Type Pressure Cell by Theodore Theodorsen, 18 pages, illustrations quarto. Washington, Government Printing Office, 1931, price ten cents.

This report relates to various improvements in the process of manufacture of the N. A. C. A. standard pressure cell. Like most pressure recording devices employing thin diaphragms, they would in general show considerable change in calibration with temperature and also some change of calibration with time or aging effect. Some instruments exhibited considerable internal friction.

It was established that the temperature dependency of the stiffness was due to difference in the thermal expansivity between the diaphragm proper and the supporting body of the cell, and convenient methods for its compensation have been developed. The diaphragm is furnished with a small central bushing of a different metal, and it is possible to determine a size of this bushing which gives the diaphragm exactly the same thermal expansivity as the cell body.

It was further established that the internal hysteresis in the diaphragm was of a negligible magnitude and that the observed lag was due, primarily, to the force of the hairspring on the stylus point. The resultant adoption of weaker hairsprings made it possible to extend the useful range of the instrument considerably downward. Satisfactory instruments having a range of less than 3 inches of water were made possible.

It was found that the tendency to change calibration with time was caused, to a great extent, by insufficient clamping of the diaphragm. The adoption of double copper gaskets improved this condition.

The required diaphragm thickness and the desirable rate of mechanical magnification have been determined on the basis of several hundred tests.

Report No. 389. The Effect of Small Angles of Yaw and Pitch on the Characteristics of Airplane Propellers, by Hugh B. Freeman, 11 pages, illustrations, quarto, Washington, Government Printing Office, 1931, price ten cents.

The subject tests were carried out in the 20-foot wind tunnel of the National Advisory Committee for Aeronautics to determine the effect on the characteristics of a propeller of inclining the propeller axis at small angles to the relative wind. Tests were made of a full-scale propeller and fuselage combination at four angles of yaw (0°, + 5°, + 10°, and + 15°), and of a model propeller, nacelle, and wing combination at five angles of pitch (− 5°, 0°, + 5°, + 10°, and + 15°).

The results of the full-scale tests of a propeller and fuselage, without a wing, show that the effect on the propeller performance is small. Similar results are shown by the model test data except that where the propeller is directly in front of the wing there is an appreciable decrease in effective thrust and propulsive efficiency with increase of angle of pitch.

Report No. 391. The Aerodynamic Characteristics of Eight Very Thick Airfoils from Tests in the Variable Density Wind Tunnel, by Eastman N. Jacobs, 14 pages, illustrations, quarto. Washington, Government Printing Office, 1931, price ten cents.

A group of eight very thick airfoils having sections of the same thickness as those used near the roots of tapered airfoils were tested in the Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics. The tests were made to study certain discontinuities in the characteristic curves that have been obtained from previous tests of these airfoils, and to compare the characteristics of the different sections at values of the Reynolds Number comparable with those attained in flight. The discontinuities were found to disappear as the Reynolds Number was increased. The results obtained from the large-scale tests in this series indicate that the N. A. C. A. 0021 airfoil, a symmetrical airfoil having a thickness ratio of 21 per cent., has the best general characteristics.

PUBLICATIONS RECEIVED.

Physical Science, An Introduction to the Specialized Courses in College Science, by Herbert Brownell, first edition, 313 pages, illustrations, maps, 8vo. New York, McGraw-Hill Book Company, Inc., 1931. Price $2.50

Analytical Mechanics, for Students of Physics and Engineering, by H. M. Dadourian, third edition-revised, 427 pages, diagrams, 8vo. New York, D. Van Nostrand Company, 1931. Price $4.00.

Andre Job, Formes Chimiques de Transition, Oeuvres recueillies par J. Perrin et G. Urbain, 355 pages, diagrams, portrait, 8vo. Paris, Société d'Êditions Scientifiques, 1931. Price 95 francs.

This Mechanical World, an introduction to Popular Physics, by Morton Mott-Smith, 233 pages, illustrations, 12mo. New York, D. Appleton and Co., 1931. Price $2.00.

The Green Leaf, the Major Activities of Plants in Sunlight, by D. T. MacDougal, 142 pages, illustrations, 12mo. New York, D. Appleton and Co., 1931. Price $2.00.

New Views of Space, Matter and Time, by J. D. Ross, 400 pages, diagrams, 8vo. Seattle, Gateway Printing Company, 1931. Price $6.50.

Technisches Wörterbuch III, Die wichtigsten Ausdrücke der Elektro- und Radiotechnik, Erster Teil Deutsch-Englisch, von Erich Krebs, Sammlung Göschen, second edition, 157 pages, 16mo. Berlin, Walter de Gruyter & Co., 1931. Price mark 1.80.

National Research Council, Transactions of the American Geophysical Union Twelfth Annual Meeting, April 30, and May 1, 1931, 229 pages, maps, Washington, National Academy of Sciences, 1931.

Royal Institution of Great Britain, Weekly Evening Meeting: February 13th, Ultrasonics: Some Properties of Inaudible Sound, by F. Lloyd Hopwood, D. Sc., 15 pages, illustrations, 8vo. May 8th, The Measurement of Noise, by G. W. C. Kaye, O. B. E., 54 pages, tables, diagrams. London, Royal Institution, 1931.

Quelques Résultats de Recherches Géologiques dans le Massif de l'Aiguille Verte, par Paul Corbin et Nicolas Oulianoff, extrait du Bulletin de la Société géologique de France, 4 pages, plates, 8vo. 1930.

U. S. Bureau of Standards, Research Paper No. 306, Accurate Measurement of Small Electric Charges by a Null Method, by Lauriston S. Taylor, 11 pages, plate, diagrams, 8vo. Washington, Government Printing Office, 1931. Price 10 cents. Research Paper No. 312, Calorimetric Determinations of Thermal Properties of Methyl Alcohol, Ethyl Alcohol, and Benzene, by E. F. Fiock, D. C. Ginnings, W. B. Holton, 19 pages, tables, 8vo. Washington, Government Printing Office, 1931. Price 5 cents.

Ontario Department of Mines, Thirty-ninth Annual Report, Investigations of Non-Metallic Mineral Resources of Ontario, 1929, 65 pages, maps, tables, illustrations, Toronto, King's Printer, 1931.

National Advisory Committee for Aeronautics, Technical Notes: No. 383, Metal-Truss Wing Spars, by Andrew E. Swickard, 31 pages, tables, diagrams, quarto, Washington, Committee, 1931. No. 384, The Effect of Injection-Valve Opening Pressure on Spray-Tip Penetration, by A. M. Rothrock and E. T. Marsh, Langley Memorial Aeronautical Laboratory, 4 pages, diagrams, quarto, Washington, Committee 1931. No. 385, Tests of Six Symmetrical Airfoils in the Variable Density Wind Tunnel, by Eastman N. Jacobs, Langley Memorial Aeronautical Laboratory, 18 pages, tables, diagrams, quarto, Washington, Committee, 1931.

U. S. Coast and Geodetic Survey, Special Publication No. 173, Latitude Redeterminations, by Frederic W. Darling, 18 pages, tables, plates, Washington, Government Printing Office, 1931. Price 10 cents.

CURRENT TOPICS

Friction of Dry Solids in Vacuo. P. E. SHAW AND E. W. L. LEAVEY. (*Phil. Mag.*, Nov., 1930.) "To measure the coefficient of friction of dry clean solids we place them," say the authors, "in a vacuum tube on which is threaded a heating coil, so that by exhaustion and repeated heating to 350° C. all lubricants as well as all surface strain can be removed from the rubbing surfaces." To value of μ, the coefficient of friction was determined by tilting from the horizontal a cylinder of material supported in two crutches of the same or of a different substance forming an X, the arms of which made 45° with the vertical and which consisted of two like cylinders having the same diameter as the supported cylinder. The vacuum tube containing the crutches and cylinder could be rotated about a horizontal axis until the supported cylinder began to slide downwards. From the angle at which motion appeared the value of the coefficient can be computed. To make successive experiments comparable care was taken that the same part of supporting and supported surfaces should be in contact in experiment after experiment. The actual sliding of the cylinder was detected by electrical contact. Alternating current was used in the heating coil to avoid magnetization in iron and nickel rods. A vacuum of about 1/100 mm. was employed in the tube surrounding the frictional surfaces. The metals examined, Fe, Ni, Cu, Ag, and Al, were rubbed with the finest sand paper and then scraped with a clean blade. Glass rods were treated with a Bunsen flame.

Before heating the value of μ was always low, between .1 and .3, and continued low after repeated evacuations and slidings. It was the application of heat that produced changes in the value of μ. "When heating commences μ falls to a minimum at about 150° C. Then, as temperature rises, it rises slowly till about 250°, then rapidly to the limiting temperature 350°. After repeated heating and cooling μ attains a constant high value. Some of our values point to the failure of the law of friction at high temperatures. Thus, for Ag-Ag and Ni-Ni at 320°, μ is about 4, so that the angle of repose is about 80°. In some cases we find the slider even becomes vertical without sliding, so that here the tangential force is finite and the normal force vanishes and $\mu = \infty$. Attention is directed to a similar effect when two Johansson gauges are "wrung" together, a very considerable force then being required to separate

them. After the full value of μ has once been reached by heating in a vacuum there are many pairs of metals for which μ is about independent of temperature. This is true for Al on Al, Cu-Cu, Ni-Ni, Fe-Fe and glass-glass, but for Ag-Ag μ rises from 2.3 at 40° to 4.2 at 360°. It is not true, however, that there is a similar rise of μ with temperature whenever silver is one of the two substances in contact. Moreover μ may increase with temperature when one metal is in contact with another even if neither shows a rise when supported by crutches of the same metal.

The authors believe that subjection to a temperature of 350° gets rid of adsorbed material and attached impurities and anneals the surfaces. Their results are different from those obtained by Tomlinson when he measured μ in the open air without the application of heat. He prepared his surfaces by scouring and polishing and consequently his surfaces were by no means in the same condition as those used by Shaw and Leavey. The latter remark "It is clear that the term 'coefficient of friction' has to be defined in terms of the history and physical condition of the reacting surface."

G. F. S.

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The Howard N. Potts Medal (Gold Medal).—This medal is awarded for distinguished work in science or the arts; important development of previous basic discoveries; inventions or products of superior excellence or utilizing important principles.

The George R. Henderson Medal (Gold Medal).—This medal is to be awarded for meritorious inventions or discoveries in the field of railway engineering.

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The Edward Longstreth Medal (Silver Medal).—This medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes. In the event of an accumulation of the fund for medals beyond the sum of one hundred dollars, it is competent for the Committee on Science and the Arts to offer from such surplus a money premium for some special work on any mechanical or scientific subject that is considered of sufficient importance.

The Louis E. Levy Medal (Gold Medal).—This medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

The Walton Clark Medal (Gold Medal).—This medal is awarded to the "author of the most notable advance in knowledge or improvement in apparatus, or in method concerning the science or the art of gas manufacture or distribution or utilization in the production of illumination, or of heat, or of power."

The Certificate of Merit.—A Certificate of Merit is awarded to persons adjudged worthy thereof for meritorious inventions, discoveries or improvements in physical processes or devices.

The Boyden Premium.—Uriah A. Boyden, Esq., of Boston, Mass., has deposited with The Franklin Institute the sum of one thousand dollars, to be awarded as premium to "any resident of North America who shall determine by experiment whether all rays of light and other physical rays are or are not transmitted with the same velocity."

For further information relating to these awards apply to the Secretary of the Institute.